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INTERCOMP

Evaluation Of Data Gathered From Unminable Coal Seams

Final Report

Prepared For

The Department Of Energy

August 1980

Contract No.
DE-AC21-79MC10641

EVALUATION OF DATA GATHERED FROM UNMINABLE COAL SEAMS

FINAL REPORT

FOR

THE DEPARTMENT OF ENERGY

UNDER

CONTRACT NO. DE-AC21-79MC10641

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By

INTERCOMP
Resource Development and Engineering, Inc.

August, 1980

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(continued)

INTRODUCTION

The work reported herein was done for the Department of Energy (DOE) under contract number DE-AC-79MC10641 dated May 8, 1979. The objective of this effort was to provide for the reduction in uncertainties in critical parameters related to the methane exploration and recovery from unminable coals in the United States.

This work is a continuation of an earlier contract (EM-78-C-21-8352). Much of the information resulting from this previous contract was summarized in the Methane Recovery from Coalbeds Section of the DOE publication "Semi-Annual Report for the Unconventional Gas Recovery Program".[1*] Because of the diverse nature of this prior effort it was reported under three separate volumes. These three volumes are briefly described below.

Volume I was entitled "Test Program To Determine The Feasibility Of Producing Methane From Unminable Coalbeds". This volume documented the development of a test program that attempted to scientifically outline the types and number of tests necessary to determine' the feasibility of producing methane from coalbeds. A numerical simulator of the coal-methane system was discussed and utilized. Costs of the test modules were developed and utilized in conjunction with the simulator results to establish optimum test procedures.

Volume II was entitled "An Analysis of Methane Potential From Unminable Coalbeds in Selected Areas of the United States". It documented the potential geologic basins that needed to be investigated for feasibility. It also delineated specific sites and companies that were contacted for their assistance during 1978 test activities.

Volume III was entitled "Analysis of Test Data Taken During 1978 Test Program -Methane From Coalbeds Project". This was the analysis of the data taken during the 1978 test program. The analysis looked at five test sites which included data from eight wells. The test procedures and techniques were discussed in the context of the overall test program. The results were compared with the simulator input which was used to develop the test program.

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*All tables, figures and references are given at the end of this report.

The current contract with DOE calls for INTERCOMP to assist in the characterization of unmineable coalbeds with particular emphasis on methane producability. This assistance is to be implemented based on the following scope of work:

1. Assist in the location of well drill sites which are most favorable for resource characterization.

2. Synthesize available data and determine standard data forms and tests.

3. Assist in the preparation of test plans for selected well sites.

4. Establish the methane production potential from coal at the test well sites, in the geologic setting, and the geographical area by: (1) using test parameter data in a computer based model to determine its effect on well deliverability (2) estimating the in-place gas, (3) estimating potential deliverability over the reservoir life, if produced.

5. Provide a relationship of the critical production parameters to the overall production economics, including gas unit prices.

6. Provide for the on-site supervision and/or monitoring the tests when required.

7. Develop an assessment of the gas producibility of the coal type and rank with respect to data parameter ranges, gas in place estimates, and well deliverability potential.

During the year of this contract, no activities took place under scope of work items 1, 2, 5, and 7. However, three instances occurred in which assistance was requested for preparation of test plans, item 3, and four test well site analysis were performed under item 4. Only one instance occurred where INTERCOMP was called upon to provide on-site monitoring of tests under item 6. The activities accomplished by INTERCOMP on these scope of work items are described in this report and conclusions reached, if any, are listed with the activity.

ASSISTANCE IN TEST PLANN-ING

INTERCOMP was asked to assist in the preparation of test plans for three selected well sites.

Confidential Well Recommendation

INTERCOMP was consulted regarding the test design and the procedures for a well identified only as "Confidential Well". After discussing the procedure proposed, INTERCOMP's only recommended change was to use abrasive-jet procedures for opening the formation to the well instead of convential perforation. INTERCOMP's experience in coal completion has been that perforations sometime seal off the coal and prevent good communication between well and formation; This not only hinders prefrac production or injection test, but sometimes hinders the obtaining of adequate injection rates during fracturing.

Waynesburg College Project Recommendation

Discussions were held concerning the water removal equipment design to be used in the DOE - Waynesburg College Project'. Estimates of the water removal necessary were 350 bpd for the multiple zone completion. INTERCOMP recommended the use of a submersible pump because experience in the DOE -Westinghouse project1 showed that these pumping mechanisms gave a lower capital cost for the volume required and the depths involved.

Arkoma Basin Sensitivity Study

A brief sensitivity study was performed on the Hartshorne coal seam found in the Mustang Production Company Barringer No. l-11 well. This well is located in Section 11 of T-4-N, R-15-W, Pittsburg County, Oklahoma. The study was done to help field engineers to design a test sequence for an Arkoma Basin Type III test'. The estimated parameters used in the simulation are shown on Table 1. Each simulation run was extended through a one year period. Sensitivity studies were done using three different values for the gas content, 186, 500, and 700 cu ft/ton. Each value for the gas content was coupled with a specific permeability. A value Of 2 md was used with the content of 186 cu ft/ton, 5 md with 500 cu ft/ton, and 20 md with

700 cu ft/ton. Evaluations were made using three fracture lengths. Figure 1 shows a comparison of three assumed gas contents for a well with no fracture. Figure 2 compares the 186 and 500 cu ft/ton cases for a fracture length of 200 ft. Figure 3 is the 700 cu ft/ton example with a 500 ft fracture. These simulations show the importance of obtaining a good hydraulic fracture. With no fracture or even with a small fracture, the production rate is very low. However, the longer fracture length coupled with the higher gas content yields a deliverability estimate in excess of 50 Mcfd.

It was not considered necessary to perform a separate study on the McAlester seam because the parameters of the two seams vary so little that there would be no significant change in deliverability.

It was planned to obtain production data from this well. An attempt was made to abrasive-jet and stimulate the Hartshorne coal seam in this well. However, because of pressure loss in the well, later determined to be a hole in the casing, the job was not performed. The well was later plugged and abandoned.

TEST SITE PRODUCTION POTENTIAL

Several sites were chosen for evaluation because methane had been produced from the coal seams. In three of the evaluations, simulations of the production history allowed determination of the important parameter data that is needed to evaluate the gas-in-place and production potential of the coalbeds in the area where the tests were performed. Information was gained from two different geological basins with two of the studies being performed at the same test site.

Penn State Coal Degasification Project

This test site was designated to study the historical production performance of three gas wells producing from the Pittsburgh Coal seam near the Cumberland Mine of United States Steel Corporation in Greene County, Pennsylvania. This site is part of the Northern Appalachian coal area.

The gas wells were drilled as part of a project sponsored by the U. S. Bureau of Mines and the Pennsylvania Science and Engineering Foundation. Description of the project and well performances are presented in two reports by Dr. Robert Stefanko, Professor of Mining Engineering, Pennsylvania State University[2,3]. The reports are entitled "Technical and Economic Problems in Methane Degasification of Coal Seams", and "The Vagarious Nature of Methane Gas From Coalbeds". Figure 4 shows the relative location of the wells and was reproduced from Dr. Stefanko's report.

The objective of the study was to determine values of the parameters thought to be important to the coalbed degasification project. Utilizing the data provided in Dr. Stefanko's reports, together with INTERCOMP's simulation experience, the three well performance histories were analyzed.

The procedure was to utilize INTERCOMP's coalbed methane simulator to model each well. The values of known parameters were fixed. These include such things as water and methane properties, coal thickness, gas content, depth, and pressure. The other variables such as permeability, porosity, diffusion coefficient, and fracture length were varied at each well until the simulated or calculated performance matched the actual performance. Table 2 gives the values of all the important parameters. Figures 5, 6, and 7 shows the performance of each of the three wells as a function of time.

It is very interesting to note that nearly the same values of reservoir parameters describe the performance of all three wells. The basic difference between wells is the length of the hydraulic fracture created. The fact that CNG 1036, which was not stimulated at this time, can be characterized by the same values of porosity, permeability, and diffusion coefficient as the other wells lend credibility to the analysis.

One drawback to this analysis is that it may not be unique. For instance, it is possible to obtain adequate performance simulations with variations in only porosity and fracture length. It may be possible to obtain adequate history matches with different combinations of porosity, permeability, and fracture lengths. However, for the purpose of this study, it is not important to know whether the porosity is 2 percent or 5 percent or whether that permeability is 10 md or 12 md. What is important is that the parameters have realistic values, and their values are relatively consistent over the area covered by the three wells. Both these conditions are necessary for coalbed degasification to be a viable energy source.

DOE - U. S. Steel Project - Pattern Analysis

The DOE - U. S. Steel Project was designated as a specific site analysis of Type III test[1] in the Warrior Basin because of the abundance of data available on the project and because of its over two years of production history. The objectives were to study interference effects between wells through simulating the production history, to predict future production, and to analyze well spacing for future pattern expansion, in addition to determining the values of the important parameters at that site.

Background

A seventeen well pattern was drilled into the lower bench of the Mary Lee Coalbed near Oak Grove in Jefferson County, Alabama. U. S. Steel is mining the same coalbed; however, the pattern is far enough away from the mine to be at least five years ahead of mining. Figure 8 shows the surface well pattern with Valley Creek running through the pattern. Subsurface depths are also indicated with suspected structural faulting. The faults indicated to the east and southeast of the pattern were shown on a core hole map used in deciding prospective mine locations. Both surface and subsurface features indicated possible faulting around well 22. The 1100 ft deep wells penetrated a 5.2 ft coal seam. Most of the wells were completed open hole and all were hydraulically fractured. Gas production began from well 22 on August 5, 1977, but the last well was not put on production until March 1, 1979. Production data was available through October 31, 19'79.

Figure 9 shows the production data for the first 700 days of operation. The first 300 days reflect production from only three wells (7, 9, and 22). As shown on Figure 8, these wells are widely spaced within the pattern and did not interfere with one another. The result is that 150 - 200 bpd of water was produced with little gas production. As soon as more wells were placed on production, the gas volumes started to increase. This is caused by interference between wells which creates large areas of pressure drawdown.

Pattern Simulation

To simulate the reservoir, a two-dimensional grid was constructed such that two grid blocks would separate each block that contained a well. Since the wells were 1000 ft apart, grid blocks in the pattern area were 333.3 ft square. The grid blocks become larger away from the well area as shown in Figure 10. Several larger grid blocks were eliminated to the east and southeast simulating the suspected barrier faults in these directions. The gradual increase in depth of the coalbed to the southeast was simulated by tilting the grid in both the x and y directions.

The data used in the simulation model came from several different sources. The equilibrium adsorption isotherm data used are shown in Table 3. The original data, taken on a sample of the Mary Lee coal was adjusted slightly to give an average gas content of 482 scf/ton at the reservoir pressure of 421 psia. The gas properties were calculated assuming methane as the major constituent of the gas. Data obtained by matching early time desorption rates from the core samples with a desorption model showed that the diffusion parameter, D/a^2, varied over several orders of magnitude. The limited values we had showed D/a^2 increased to the east. Using the same trend, values used in this simulation ranged from 1×10^{-10} to 1 x lo-ll sec^{-1}. A relative permeability curve was developed during the matching process which has a critical gas saturation of 20 percent as shown in Figure 11.

The primary unknown variables in making the history match were the porosity and the permeability. During the early matching process, porosities as high as 5 percent were used for the whole pattern. However, to enable gas saturations to build up high enough to flow gas in most wells, the porosity was eventually lowered to 1.2 percent. Early matching attempts used permeabilities as low as 3 md. Low permeabilities did not allow enough interference between wells and caused the well blocks to decline in pressure too rapidly. A permeability of 75 md over most of the area corrected this problem although this had to be increased in some areas. Figure 10 shows areas in which the permeability and porosity were adjusted above these normal values.

The model was initialized with the ‘fracture system saturated with water. The gas content of the coal was at equilibrium with the initial pressure of 421 psia. The individual wells were simulated by a point source at the center of the grid block where the well is located. The wells were subsequently produced by specifying a water production rate consistent with the wells demonstrated pump capacity. Limiting bottomhole pressures were calculated from liquid level determinations and surface pressures. The well then produced pump capacity or reservoir deliverability against the calculated limiting pressure. The gas-water ratio was then determined by the relative permeabilities of the two phases in the grid block containing the well. The limiting bottomhole pressures were decreased in a stepwise manner consistent -with the measured decline in the wells.

The individual wells were assigned production rates at times corresponding to actual ‘first production. The major shut in periods were simulated by periods of zero flow.

Simulation Results

The simulation results for the pattern are shown plotted with the actual production in Figure 12. The simulation agrees quite well with the total production from the pattern. The comparisons of simulation with actual production rates from each well are shown in Figures 13 through 29. A few of these wells will be discussed to illustrate the capabilities of building into the simulation model certain geological and operational features necessary to understand why the wells perform as they do.

For instance, well 22 produced at a fairly constant high water rate and low gas rate. The actual and simulated production rates are shown in Figure 26. The high water rate compared to other wells in the pattern could indicate a source of water other than that normally in the immediate vicinity of the well. This model allowed us to simulate an area of increased porosity and permeability in the same general area as the possible faulted zone indicated on Figure 8.

As a different example, well 4 indicates an immediate gas rate response when the well is turned on with the water rate falling off rapidly. See Figure 14. This indicates the possibility of a barrier near the well which causes rapid pressure drawdown along with increased gas saturation. The two faults shown to the east and southeast of the well pattern on Figure 8 could cause this phenomena. In the model, the symmetrical grid was ended at grid block 21 and the other blocks eliminated on the southeast to simulate these barrier faults.

Well 7, shown in Figure 17, is located inside the pattern. Its high gas rate beginning after 582 days is indicative of the effect of surrounding wells being placed on production creating interwell interference. Pressure interference between wells results in a rapid lowering of the pressure between wells. Thus, the gas was released at the maximum rate allowable in this interwell area. This well was probably effected by the previously discussed well 4, among others. The high permeability in the area of wells 3, 4, 7, and 8 was necessary to obtain this type of interference. Actually, during fracturing, communications were demonstrated between wells 4 and 7.

Not all the individual wells were good matches. For instance, well 25, shown in Figure 29 shows that the computed water rate was low. However, looking at the well data, it produced at a very low rate even though the water rate remained high. One reason for this is the well is an outside well in the pattern; thus, it was not subjected to as much interference as internal wells. Limited echometer data indicated that this well was not being pumped off and thus retained a high fluid level in the well. The porosity in the area of the field was increased to provide more water to be produced before the critical gas saturation was reached. The well finally started producing gas after 735 days when the well began to be pumped off as indicated by the fall off in water rate starting at this time.

Performance Prediction

The relatively good match of individual well production rates and the excellent match of the total pattern production rates give credence to predicting what the pattern will produce in the future. Figure 30 shows the result of continuing to produce the model for 20 years into the future. It can be seen that after only a few months of continued increase in gas production, the rate begins to decline. However, a stable rate of about 400 Mcfd is predicted after nine years of production. This rate continues through the remainder of the 20 year period and the recovery at that time is calculated to be 3.8 Bcf of gas. At the end of 20 years, about 77 percent of the producible gas was removed from the area covered by the 17 well pattern. This means that approximately 2.6 Bcf of the gas was produced from the area outside the limits of the pattern.

At the end of six years, which corresponds to the projected time of mining, approximately 45 percent of the producible gas will be removed from the area covered by the 17 wells. This amount of removal will materially reduce the methane emissions anticipated during mining. Further, the gas recovered is at a rate that is significant from a gas supply standpoint and should be sold or utilized.

This example demonstrates that gas can be recovered from coalbeds at rates that can materially affect the gas content of coal ahead of mining. Further, this rate is significant for a gas supply.

Well Spacing

Because the project is planning to drill additional wells adjacent to the existing pattern, some additional simulations were made to evaluate the effect of well spacing in this coalbed. To do this, we assumed four different spacing patterns. The 160, 90, and 23 acre runs simulated patterns of over 50 wells. The 40 acre well spacing run simulated on a sixteen well pattern.

The basic parameters used in these runs were either taken directly from, or typical of, the parameters used in the final Oak Grove Pattern simulation discussed above. The only major exception was that the coalbed was considered as homogeneous, thus averaging out the inhomogenities as would occur in large pattern developments. The basic physical parameter data used are listed in Table 4.

In the four cases presented, the main difference was the number and spacing of the wells. The table below shows the differences between the runs.

Case No.	Well Spacing (Acres)	No. of Wells	Area in Pattern (Sq. Miles)	Area In Simulation (Sq. Miles)
1	160	64	16.00	366
2	90	100	13.14	366
3	40	16	1.00	366
4	23	64	2.30	366

The 23 acre case was chosen specifically to duplicate the well spacing used in the Oak Grove pattern. It can be seen by the production data at the end of 20 years, given below, that more gas per well will be produced by the 160 acre well spacing than by the 23 acre well spacing.

Case No.	Total Gas Production (BSCF)	Total Gas Per Well (MMSCF)	Total Gas Per Well Per Acre in Pattern (MSCF)	Portion of Gas Prod. From Outside Pattern (Percent)
1	37.38	584.02	228.1	19.07
2	38.81	388.12	184.6	29.33
3	4.97	310.37	1,939.8	72.98
4	10.63	166.11	45.3	53.53

The effect of more wells in the pattern can be seen in the above table. Case 3 is shown to give a very high gas recovery per well in the pattern. However, the last column shows that due to the small number of wells in the pattern, more than seventy percent of the gas produced came from outside of the pattern. When the number of wells is increased, the amount of gas drawn in from outside the pattern becomes a smaller proportion of the total gas produced.

The effect of the well spacing on gas production from the five foot coal seam is graphically illustrated in Figure 31. The 160 acre spacing gives more gas recovery per well than any of the smaller spacing from two years to twenty years. If this were related to economics, it is obvious that the 160 acre well spacing would give a better payout for each well drilled.

However, if the purpose of the pattern is degasification for coal mining, the importance of long term total gas production per well is less. The curve for one year in Figure 31 shows that the 90 acre well spacing gives more gas per well than the 160 acre well spacing case. This illustrates that the closer well spacing causes well interference to take place earlier in the pattern life. By plotting the percent gas recovery from within the pattern area versus time, as shown in Figure 32, it can be seen that the smaller spacing will remove a larger percentage of the gas from within the pattern. Since the 40 acre spacing simulation included such a small number of wells, it does not follow the trend of the other cases. This illustrates the need for more wells in the Oak Grove Pattern.

Conclusions

The following conclusions can be drawn for the Oak Grove Pattern analysis:

1. INTERCOMP's "Implicit Gas-Water Model With Absorbed Gas Option" can be used to simulate the production history of a multiwell pattern of coal degasification wells.

2. Pressure interference between coal degasification wells is an important factor in gas production.

3. Gas can be recovered from coalbeds at rates that can materially affect the gas content of coal ahead of mining. Further, this rate is sufficient for a gas supply.

4. If economic gas production is the purpose of coal degasification, a larger well spacing is desirable.

5. If degasification of a specific coal area for the purpose of mining is the major objective, a smaller well spacing is desirable.

DOE - U. S. Steel Project - Single Well Analysis

In August, 1979, a report was prepared for the Department of Energy entitled "Evaluation of a Coalbed Degasification Production Test"[4] under con tract number DE-AP22-79PC12196 by INTERCOMP, Inc. This report analyzed test data for the first 140 days of production from well 22 of the Oak Grove degasification pattern described in the previous section. The necessity for a reevaluation of the results of the previous study became apparent when it was discovered during the pattern simulation that information concerning the background of the data supplied was interpreted erroneously.

Data Interpretation

The data that was misinterpreted was the daily water production information supplied as shown in Figure 33. It was assumed that once the water production was increased from 80 to 108 bpd, the pump was capable of delivering that water rate indefinitely. Therefore, it was thought the subsequent fall off in water production was due to the fact that the reservoir was unable to yield that much water. In order to simulate a reservoir with such a capability, it was necessary to set values for the unknown parameters low enough to allow the water production to fall off at this early stage. These were a porosity of 2.8 percent, a permeability of 3 md, a fracture length of 790 ft, and a diffusion coefficient of 1 x 10^{-10} sec^{-1}.

Upon receiving updated information concerning daily production rates of well 22, it was determined that the well did not actually drop in rate due to natural reservoir depletion. In fact, the well was able to produce water at virtually its initial rate throughout its entire three year production history. See Figure 26. It was discovered that the drop off in the water rate that had been assumed to be a natural phenomena, was actually due to a loss of pump efficiency. This occurred because there was a concentration of sand in the water which was abrasive enough to wear down the cups in the pump causing a loss in pump efficiency. With this revelation in mind, the simulation was reevaluated.

Simulation Re-Evaluation

The new simulation was performed by setting the well to produce 80 pbd of water up to the 40th day. At this point, the rate was increased to 108 bpd. The well was produced at this rate for 12 days, at which time the loss in pump efficiency was encountered. The well was set back to a rate of 80 bpd and allowed to produce at that pace for the remainder of the study. Adjustments were then made in the unknown parameters to reproduce the performance of the gas rate. The final match is shown in Figure 34. The values for the unknown parameters that were determined by the simulation are a porosity of 1.8 percent, a permeability of 85 md, a fracture length of 40 ft, and a diffusion coefficient of 2.0 x 10^{-8} sec^{-1}. These values more closely represent the numbers determined by tests run on the coal. The ramifications of this new, higher values for the diffusion coefficient are great. A diffusion coefficient of 1 x 10^{-10} indicates a very low overall recovery. The high value of 2 x 10^{-8} coupled with a greater permeability show that the coal should produce more gas than was originally thought.

A major change from the previous history match was the discovery of a highly permeable fault zone located approximately 1000 ft from the well bore, see Figure 35. Prior to the installation of this fault in the model, the simulation showed the well producing quantities of gas much greater than actually occurred in the later stages of production from January, 1978, on. Once the fault was added, there was no subsequent surge in the gas rate and a close approximation of the actual history was achieved. Water bearing faults in this same coal seam have been mined through in an area several miles to the southwest of this well.

Conclusions.

The conclusion to the initial report showed that the probability of an economically successful project was slight, due to the low deliverability of the coal. The fact that this conclusion was found to be in error makes the prospects for the area much more hopeful. In fact, well 22 is one of the few wells in the pattern that is producing at such an insignificant rate. We are now confident that this is due to the large supply of water in close proximity to the well. Whenever this situation is present, it makes gas production difficut because of the inability of the well to deplete water from any of the surrounding areas where the majority of the gas is in place.

Kinloch Development Corporation,

In September, 1979, INTERCOMP transmitted to DOE a report entitled "INTERCOMP Summary of Activities for Kinloch Deveiopment Corporation in 1978". A summary of the work done and results obtained at this test site is given herein. The reports from the desorption tests, the log interpretation, and the fracturing, are given as appendicies in the original report.

As part of a potential ongoing drilling program in Greene County, Pennsylvania, Kinloch Development asked INTERCOMP to assist with technical aspects of the program. The project was designed to test for oil or gas production. Recognizing that the gas content of the coalbeds is a large part of the resource, INTERCOMP recommended a procedure to determine the gas content of the various seams.

Gas Desorption Tests

This procedure was to take sidewall cores of the coal, immediately seal the cores in cannisters, and ship to a commerical laboratory for analysis. The first well to be sampled in this. manner was the Stoner No. 1. Unfortunately, the shipping logistics forced a time delay and early time data was not obtained. However, the gas content was able to be estimated. The second well, Murdock No. 1, also experienced difficulties in that it had hole problems and the Allegheny series coals were below a bridge. It was impossible to sample below the Pittsburgh coalbed at 658 feet. The results of these measurements are shown on Table 5. Five samples were taken from the Stoner No. 1 and two samples from the Murdock No. 1. The results show consistent results with the gas content increasing with depth.

Since all the lab data are reported in units unusual to petroleum engineering, INTERCOMP prepared a chart shown as Figure 36 to convert these units to common field units. This chart show the gas-in-place as a function of gas content and coalbed thickness. The five samples from the Stoner well are ‘shown on the chart and represent a total of 34 ft of coal with a combined gas content of 14,430 Mcf/acre. If a well were drilled on 100 acre spacing, the gas-in-place would be 1.443 Bcf. A similar analysis of the Murdock No. 1 was not possible because of the problems with the bridge in the well at the time of sampling.

The correlation of the coals is shown on Figure 37. The coalbeds correlate quite well except the Upper Freeport that is approximately 10 ft thick at the depth of 1000 ft in the Stoner No. 1 is missing completely in the Murdock No. 1.

The upper coals of the Conemaugh series are unavailable for testing because of legal problems.

Prefrac Tests

The coal seams at 1340, 1398, 1424, and 1485 ft, were perforated in the Murdock No. 1. The perforating was done with the water level at approximately 1000 ft such that a differential pressure would exist into the wellbore at the time of perforating.

After perforation, the well was monitored for fill up with water. When none was observed, the well was acidized with 1000 gal of 15 percent acid. Following the acid treatment, there was flow into the well.

On June 1, 1978, a constant rate injection test was run on the well. A constant rate of 1.4 bpd of fresh water was injected into the well and surface pressure recorded as a function of time. The data are shown in detail on Table 6 and plotted on Figure 38.

Analysis of the data assuming single phase water flow yields a permeability-thickness product of 1.9 md-ft. The data indicate some irregularities in the pressures at about 200 minutes. These are thought to be the effects of the multiple sets of perforations. This means that the excellent straight-line portion of the curve probably represents only a single coal seam. This also means that the permeability is in the range of 0.5 to 1.0 md depending on which zone was open at the time.

Table 7 is the pressure fall off data subsequent to the injection test. This data, when plotted on a "Horner Plot", extrapolates to a static water level of about 400 ft, which would give an initial pressure of 409 psig at the top perforation of 1341 ft.

Postfrac Tests

On June 7, 1978, the Murdock No. 1 was stimulated with a hydraulic fracture treatment using the patented Kiel Process. This process uses a staging technique that is designed to create highly conductive fractures. The treatment was designed as a limited entry technique which uses a controlled number of perforations to ensure that all zones are stimulated. The treatment was designed for 5,000 bbl of water containing 32,000 lb of 80/800 mesh sand and 50,000 lb of 20/40 sand. The design was to achieve an injection rate of 40 bpm at the design pressure of 1800-2000 psi. The design was to include eight stages of approximately 650 bbl each.

After breaking down the formation using ball sealers, the stimulation was started. The design injection rate was never achieved because of higher than anticipated injection pressures. The maximum allowable pressure on the casing was 3900 psi and as a consequence, the injection rate was necessarily curtailed. The first stage of 650 bbl was achieved at a rate of approximately 26 bpm and pressure of 3800-3900 psi. Because of the high pressures, the second and third stages were shortened, and the job was terminated after the third stage. Total volume pumped was 1533 bbl containing 18,480 lb of 80/100 mesh and 15,750 lb of 20/40 mesh sand.

The well was allowed to flow back for several days before the well was swabbed and what sand flowed back was cleaned out. The well produced approximately 80 bpd of water with a show of gas that would flare occasionally.

Before running the pump, a series of injection tests were run using a packer. The packer was set on tubing between the third and fourth sets of perforations. A constant rate injection test was run down the tubing. The packer was then moved to between the second and third sets of perforations and another injection test run down the tubing, thus injecting into the third and fourth sets of perforations simultaneously. Then an injection test was run down the annulus, injecting into the first and second sets of perforations. The packer was then moved to between the first and second sets of perforations and a fourth injection test was run down the annulus into the first zone alone.

These tests were of necessity very short-term, and little quantitative information could be computed with regard to fracture length, etc. However, it did show that all zones with the exception of the third zone showed a marked improvement over the prestimulation injection test. This means that at least three of the four zones were stimulated.

A sucker rod pump was set below the bottom perforations and production started. The result was water production with some gas. The pumping unit engine was converted to run on gas from the well. The well was pumped intermittently for several weeks with some gas flow. INTERCOMP recommended the installation of gas and water meters to quantitatively test the well, but to our knowledge, this recommendation was never implemented.

ON-SITE TEST MONITORING

The contract scope of work includes the provision for INTERCOMP to provide on-site supervision and/or monitoring of the test when required. Only once during this contract period was this requested. In January, 1980, an INTERCOMP engineer was on hand when an attempt was made to abrasive-jet and fracture the Hartshorne coal seam in the Mustang Production Company Baringer No. 1-11 well. Because a hole in the casing was discovered during the initial stages of preparing to abrasive-jet the well, the job was never completed.

RESOURCE ASSESSMENT

As described in scope of work, INTERCOMP is to develop an assessment of the gas producibility of the coal type and rank with respect to data parameters ranges, gas in place estimates, and well deliverability potential. An updated tabulation of 1979 test data was received and shown in synopsis form in Table 8. This data is discouraging because of very low gas content values. For this reason, the resource assessment study was suspended until more complete data is available. Additional data has not been received.

OTHER ACTMTIES

Some activities performed by INTERCOMP related to the overall DOE Methane From Coal Project. The following activities were requested by DOE.

Emerald Mine Consultation

In April, 1980, INTERCOMP met with DOE and J & L Emerald Mine Corporation personnel to discuss the technical aspects of the Directional Drilling Degasification Test Project in Grene County, Pennsylvanial. Three horizontal holes have been bored from the bottom of a single angled hole drilled from the surface to the coalbed. A vertical dewatering well was drilled to intersect the coalbed at the junction of the angled hole and the horizontal holes. The purpose of this dewatering well was to pump water from the horizontal holes, but it was not accomplishing this purpose. The results of the discussions led to the conclusion that the dewatering well has some sort of completion problem. Some buildup and fall off data taken from the obseration wells in the pattern have been received by INTERCOMP as a result of this meeting. Hopefully, this data can be analyzed for reservoir permeability and possibly for system compressibility in the future.

Symposium On Methane From Coal

The manager of INTERCOMP's effort under this contract attended the one day symposium on DOE's Methane Recovery From Coalbeds Program held in Golden, Colorado on January 30, 1980. Although he did not give a presentation, discussion with other attendees provided valuable input to the current effort on this contract.

Paper Presented

Mr. Ken Ancell presented the paper SPE/DOE 89'71 entitled "Analysis of the Coalbed Degasification Process at a Seventeen Well Pattern in the Warrior Basin of Alabama"[4], by K. L. Ancell, S. Lambert, and F. S. Johnson, at the 1980 SPE/DOE Symposium on Unconventional Gas Recovery held in Pittsburgh, Pennsylvania, May 18-20, 1980. Interest in the paper was indicated by questions asked both during the discussion period and after the session.

REFERENCES

1. Manilla, R. D., Editor: "Semi-Annual Report for the Unconventional Gas Recovery Program", Period Ending September 30, 1979, DOE/METC/SP-2, USDOE, Morgantown, West Virginia (April 1980) 25-193.

2. Stefanko, Robert: "Technical and Economic Problems in Methane Degasification of Coal Seams", MERC/SP-78/1, Proceedings From Methane Gas From Coalbeds - Development, Production, and Utilization Symposium, Coraopolis, Pennsylvania, January 18, 1978, 79-96.

3. Stefanko, Robert: "The Vagarious Nature of Methane Gas From Coalbeds", METC/SP-79/9, Proceedings of the Second Annual Methane Recovery From Coalbeds Symposium, Pittsburgh, Pennsylvania, April 18-20, 1979, 45-55.

4. INTERCOMP Resource Development and Engineering, Inc.: "Evaluation of a Coalbed Degasification Production Test", Unpublished report prepared for the Department of Energy under Contract No. DE-AP22-79PC12196 (August, 1979).

5. Ancell, K. L., Lambert, S., and Johnson, F. S.: "Analysis of the Coalbed Degasification Process at a Seventeen Well Pattern in the Warrior Basin of Alabama", SPE/DOE 8971, Proceedings from SPE/DOE Symposium on Unconventional Gas Recovery, Pittsburgh, Pennsylvania, May 18-21, 1980, 355-369.

TABLES

TABLE 1

ESTIMATED PARAMETERS FOR MUSTANG BARRINGER WELL COAL SEAMS

	McAlester	Hartshorne
Thickness, ft	3.6	3.1
Depth, ft	3213.4 - 3217.0	4629.6 - 4632.7
Gas Content, cu ft/ton*	186	186**
	—	500**
	—	700**
Reservoir Pressure, psia	Hydrostatic	2000
Permeability, md	—	2
	—	5
	—	20
Porosity, percent	4	4
Desorption Coefficent	—	$1x10^{-10}$
Rank	High volatile A bituminous	High volatile A bituminous

* Desorption in progress
** Based on U.S. Bureau of Mines data

TABLE 2

SUMMARY OF PARAMETERS

PENN STATE DEGASIFICATION PROJECT

Wells	CNG 1034	CNG 1035	CNG 1036
Cumulative Production			
4/1/77 to 2/1/79			
Gas - Historical, Mcf	2,300	9,200	1,760
Gas - Modeled, Mcf	2,273	9,516	2,116
Water - Historical, bbl	30,800	31,000	12,360
Water - Modeled, bbl	30,640	31,920	13,136
Average Permeability, md	10	10	10
Average Porosity, fraction	.03	.02	.02
Initial Pressure, psia	375	375	375
Length of Half Fracture, ft	500	250	0
Initial Gas Content, cu ft/ton	268	268	268
Effective Drainage Radius, ft	1000	900	900
Gas-in-Place, MMcf	316	256	256
Water-in-Place, Mbbl	135	50.6	50.6
Diffusion Coefficient, sec^{-1}	$1x10^{-10}$	$1x10^{-10}$	$1x10^{-10}$

TABLE 3

EQUILIBRIUM **ADSORBTION ISOTHERM** DATA
USED IN SIMULATION, OAK GROVE PA'ITERN

Pressure (Atm)	Gas Adsorbed (Std cc/g)
0.0	0.00
5.0	4.21
10.0	7.61
15.0	10.43
20.0	12.79
25.0	14.80
30.0	16.54

TABLE 4

BASIC **PARAMETERS USED IN OAK GROVE WELL SPACING SIMULATIONS**

Water compressibility = 3.0 x 10^{-6} l/psi

Rock compressibility = 3.0 x 10^{-6} l/psi

Water formation volume factor = 1.0 RB/STB

Formation water density = 65.0 lbs/cu ft

Gas gravity (air = 1.0) = 0.65

Water viscosity at reservoir conditions = 0.85 cp

Gas formation volume factor = Normal methane curve

Gas viscosity = Normal methane curve

Gas-water relative permeability curve = Figure 11

Critical gas saturation = 20 percent

Absolute permeability (both directions) = 75 md

Porosity = 2 percent

Reservoir dip = 0 degrees

Depth = 650 feet below sea level

Initial pressure = 421 psia

Depth to water-oil contact = 650 feet below sea level

Mean particle radius = 1.0 cm

Diffusivity = 2 x 10^{-10} sq cm/sec

Coal density = 1.35 g/cu cm

Equilibrium adsorption isotherm = Table 3

Gas content of coal in initial conditions = 21.7036 scf/cu ft of coal

Coal thickness = 5 ft

TABLE 5

SUMMARY OF GAS CONTENT MEASUREMENTS
KINLOCII DEVELOPMENT CORPORATION

	Stoner No. 1		Murdock No.1	
Coal Seam	Depth ft	Gas Content cc/g	Depth ft	Gas Content cc/g
Waynesburgh			329-333	1.04
Pittsburgh	422-426	3.3	658-664	1.95
Bakerstown	825-826	7.6		
U. Freeport	1003-1005	8.3		
M. Kittanning	1155-1156	6.7		
L. Kit tanning-Clarion	1181-1244	13.3		

TABLE 6

CONSTANT RATE INJECTION TEST
KINLOCH DEVELOPMENT, MURDOCK NO. 1
June 1 and 2, 1978

Hole Loaded 9:00 am - Generator would not work.
At 1:00 pm water level 5 ft below ground level.

Time	Pressure psig
1:07 pm	0.0
1:10	4.0
1:12	6.5
1:17	10.0
1:20	18.0
1:20	18.0
1:25	30.0
1:36	53.0
1:39	58.0
1:42	65.0
1:47	71.5
1:52	78.0
1:57	83.5
2:03	90.0
2:08	94.5
2:12	97.5
2:17	101.0
2:22	104.0
2:27	107.5
2:37	112.0
2:49	117.0
2:57	
3:00	122.0
3:17	129.0
3:47	140.0
4:17	148.0
4:40	140.0
4:47	141.0
5:02	144.0
5:22	147.0
5:37	150.0
5:47	152.0
6:12	158.0
6:17	162.0
6:27	167.0
6:42	173.0
6:57	178.0
7:22	183.0
7:37	182.0
7:47	180.0

TABLE 6 - continued

CONSTANT RATE INJECTION TEST
KINLOCH DEVELOPMENT, MURDOCK NO. 1
June 1 and 2, 1978

Shutdown 3 minutes to add oil.

Time	Pressure psig
7:50	162.0
8:02	174.0
8:14	179.0
8:47	184.0
9:07	188.0
9:17	190.0
9:27	192.0
9:37	194.0
9:47	196.0
10:07	202.0
10:17	204.0
10:27	207.0
10:47	209.0
11:12	214.0
11:47	219.0
12:12 am (June 2)	224.0
12:27	225.0
1:17	232.0
1:27	229.0

TABLE 7

PRESSURE FALL OFF TEST
KINLOCH DEVELOPMENT, MURDOCK NO. 1
June 2, 1978

Time	Pressure psig
1:29 am	229.0
1:30	225.0
1:31	223.0
1:32	217.0
1:33	211.0
1:34	207.0
1:35	201.0
1:37	191.0
1:39	182.0
1:42	170.0
1:45	160.0
1:50	143.0
2:02	108.0
2:10	93.0
2:20	73.0
2:30	59.0
3:05	19.0
3:20	10.0
3:26	7.0

TABLE 8

1979 WELL TESTING ACTIVITIES THROUGH SEPTEMBER 1, 1979

SUMMARY SHEET

Total Number of Well Tests

Type I - 10

Type III - 1

Total Feet Cored	- 673 ft
Total Coal Cored	- 190 ft
Number of Desorption Samples	- 48
Range of Gas Contents	

Basin	Gas Content (cu ft/ton)
Illinois	16 - 29
Arkoma	170
Piceance Creek	17.5 - 65.5
Warrior	—
Powder River	Extremely Low

FIGURES

FIGURE 1

MUSTANG BARRINGER WELL, HARTSHORNE SEAM, FRACTURE = 0 FT.

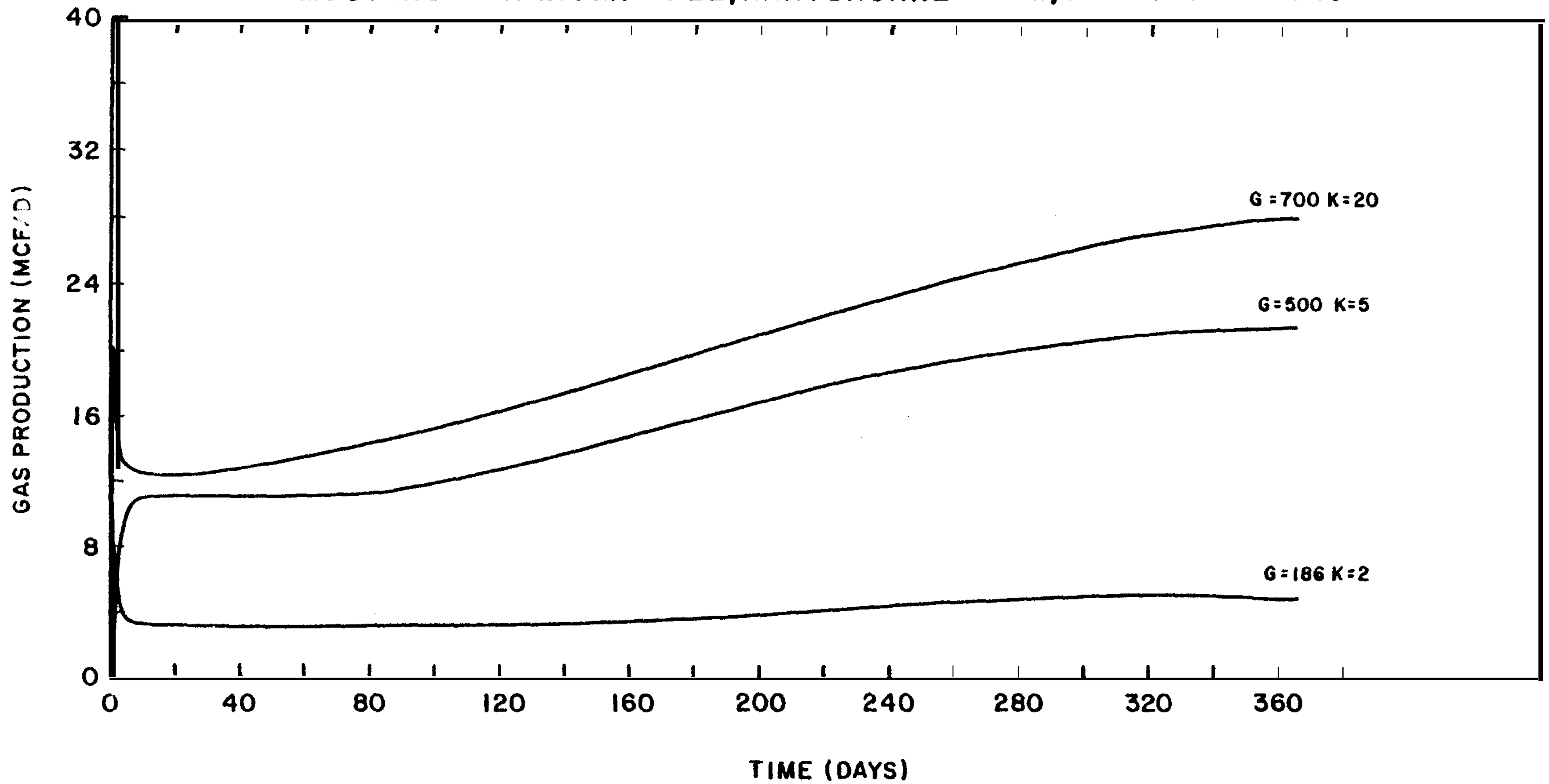


FIGURE 2
MUSTANG BARRINGER WELL, HARTSHORNE SEAM, FRACTURE = 200 FT.

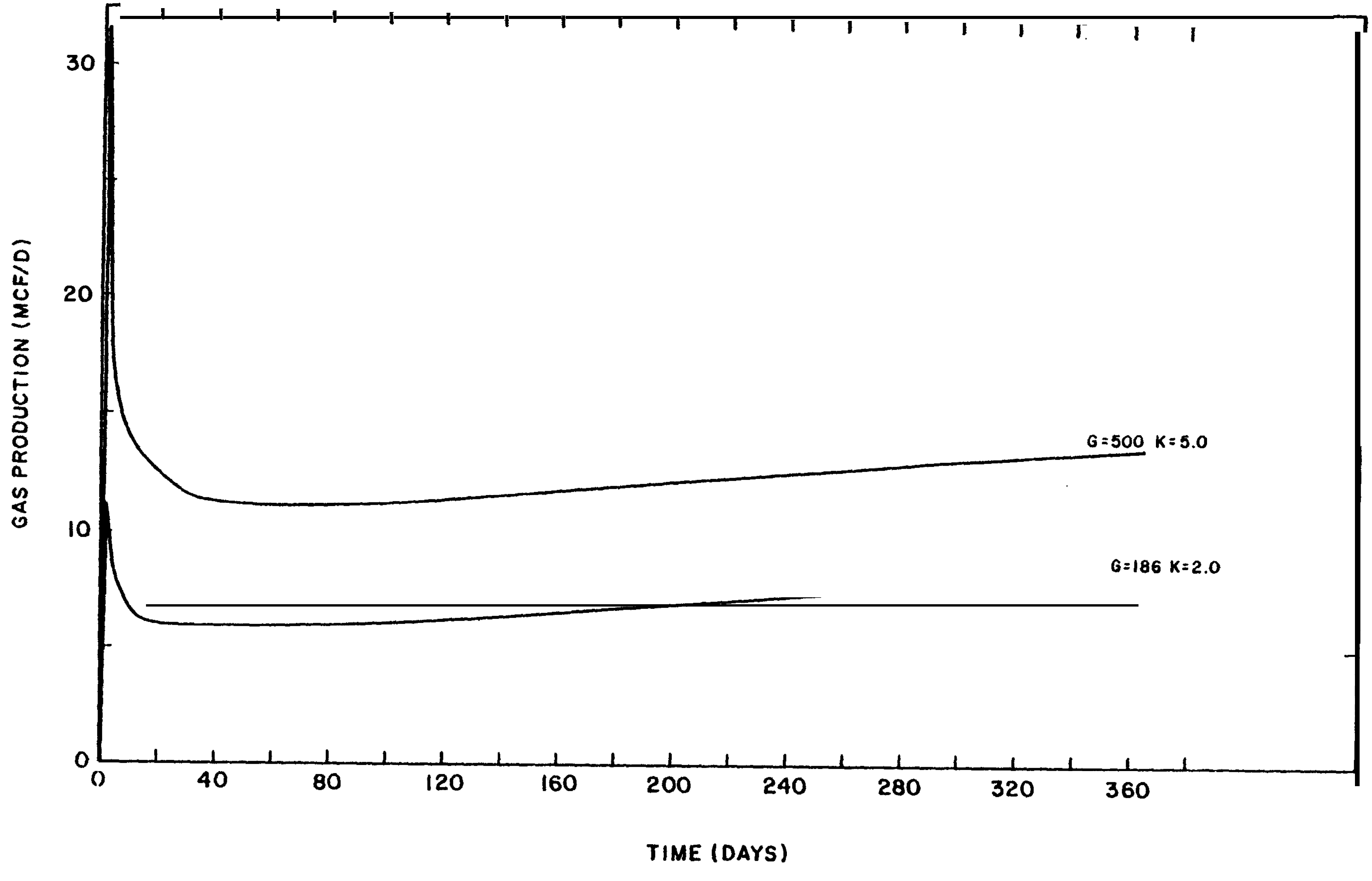


FIGURE 3

MUSTANG BARRINGER WELL, HARTSHORNE SEAM, FRACTURE = 500 FT.

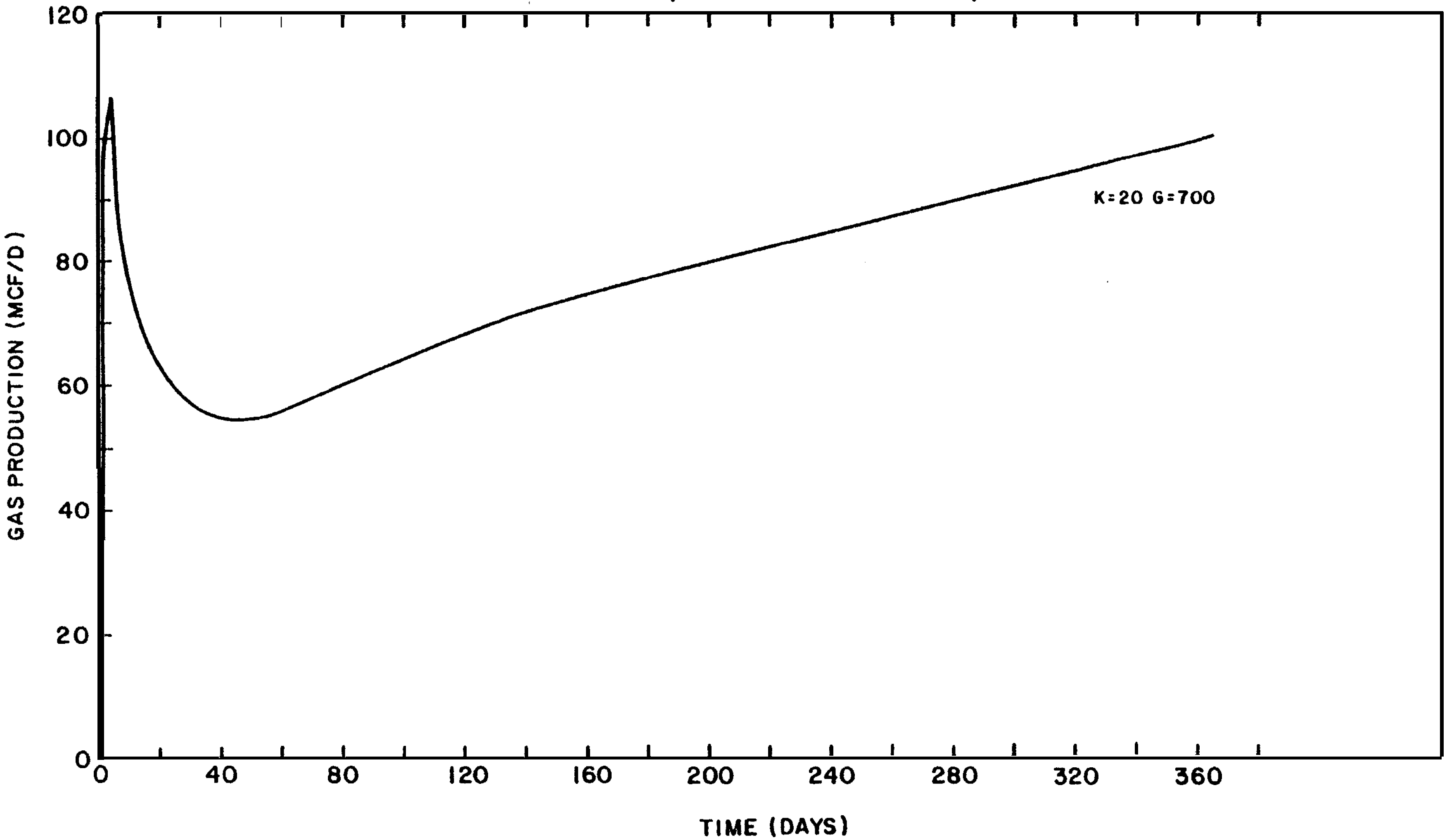


FIGURE 4.

DEGASIFICATION HOLE ARRANGEMENT at CUMBERLAND MINE

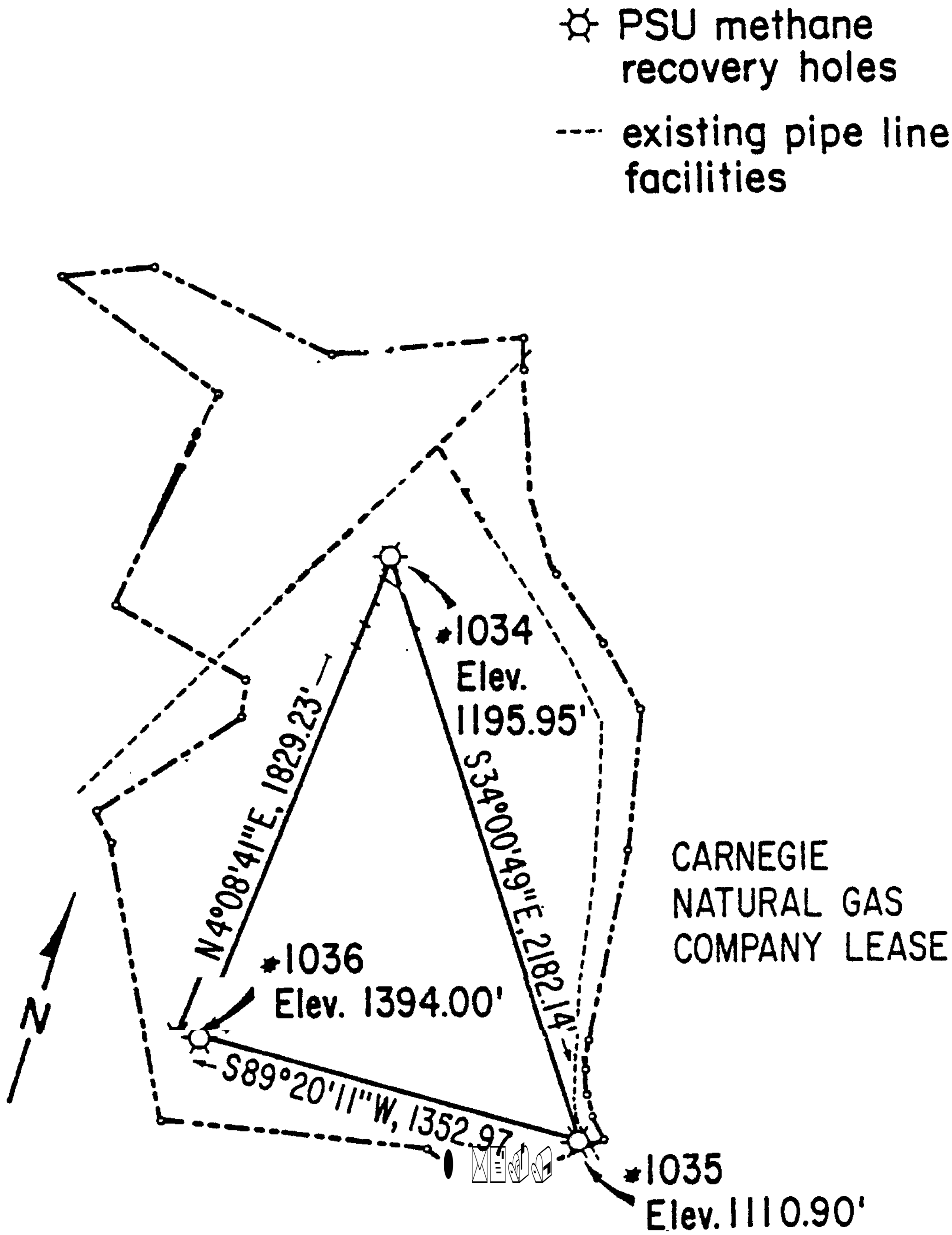


FIGURE 5
PERFORMANCE CURVES - WELL CNG 1035

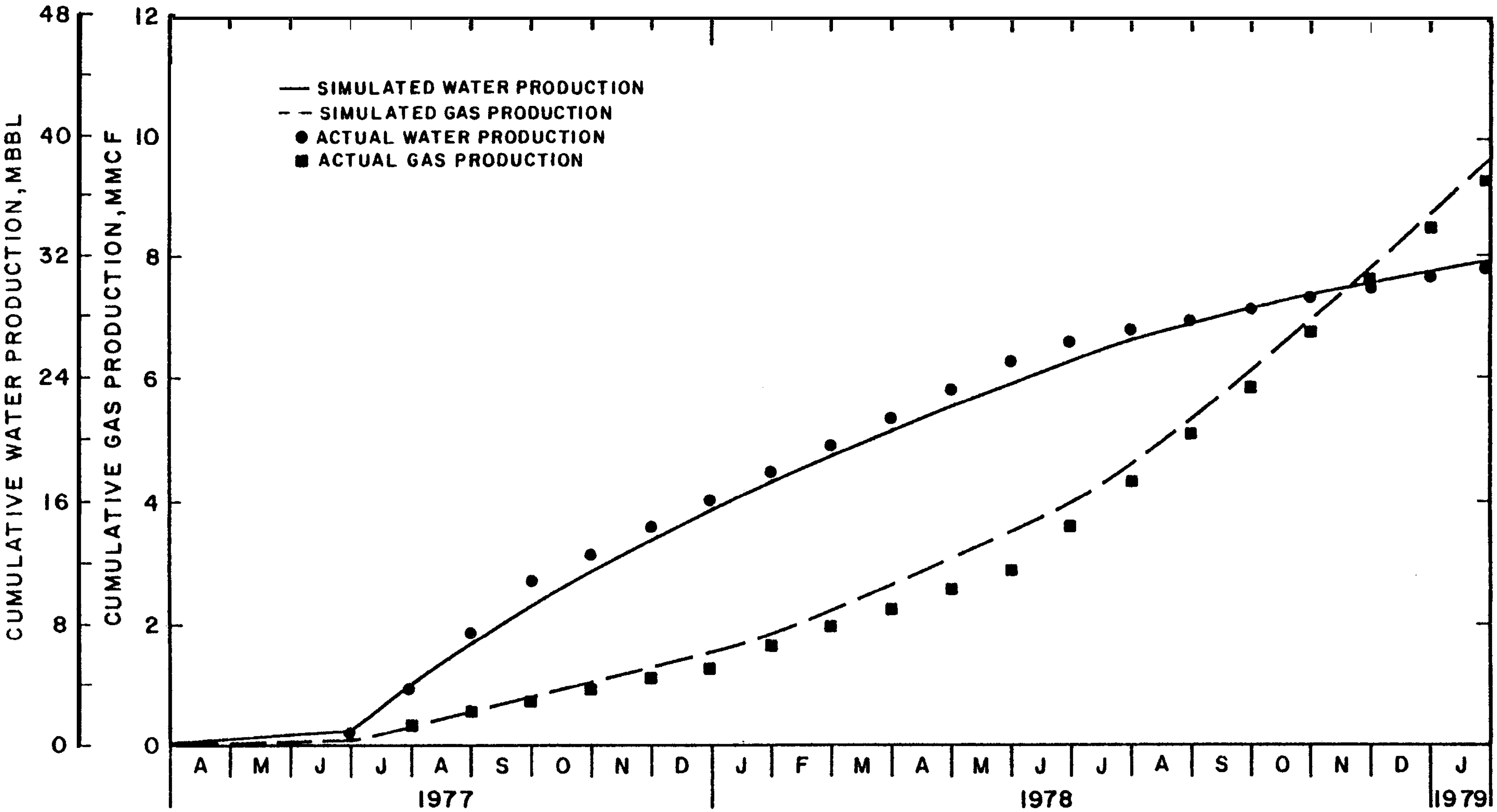


FIGURE 6
PERFORMANCE CURVES - WELL CNG 1034

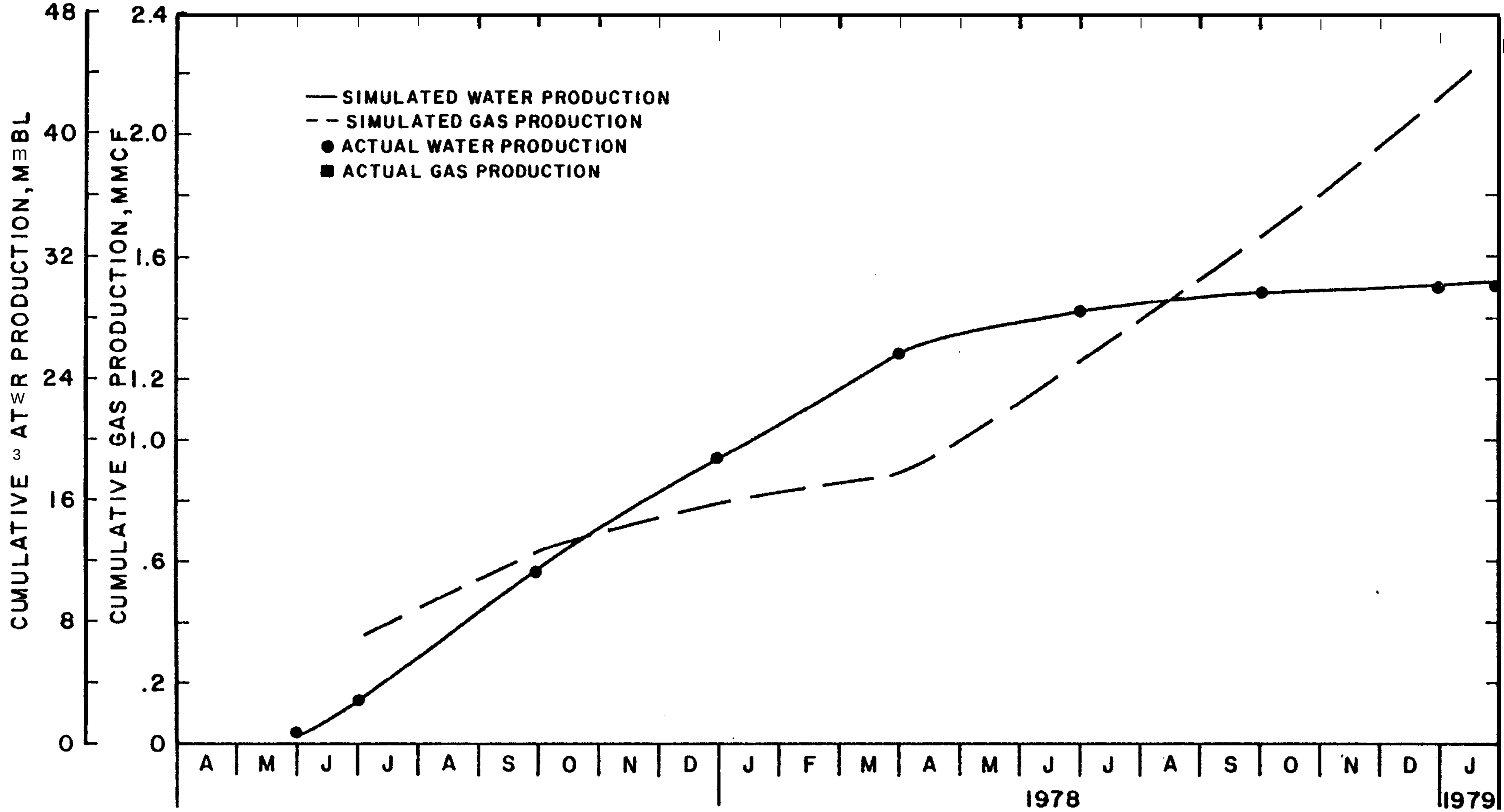


FIGURE 7
PERFORMANCE CURVES - WELL CNG 1036

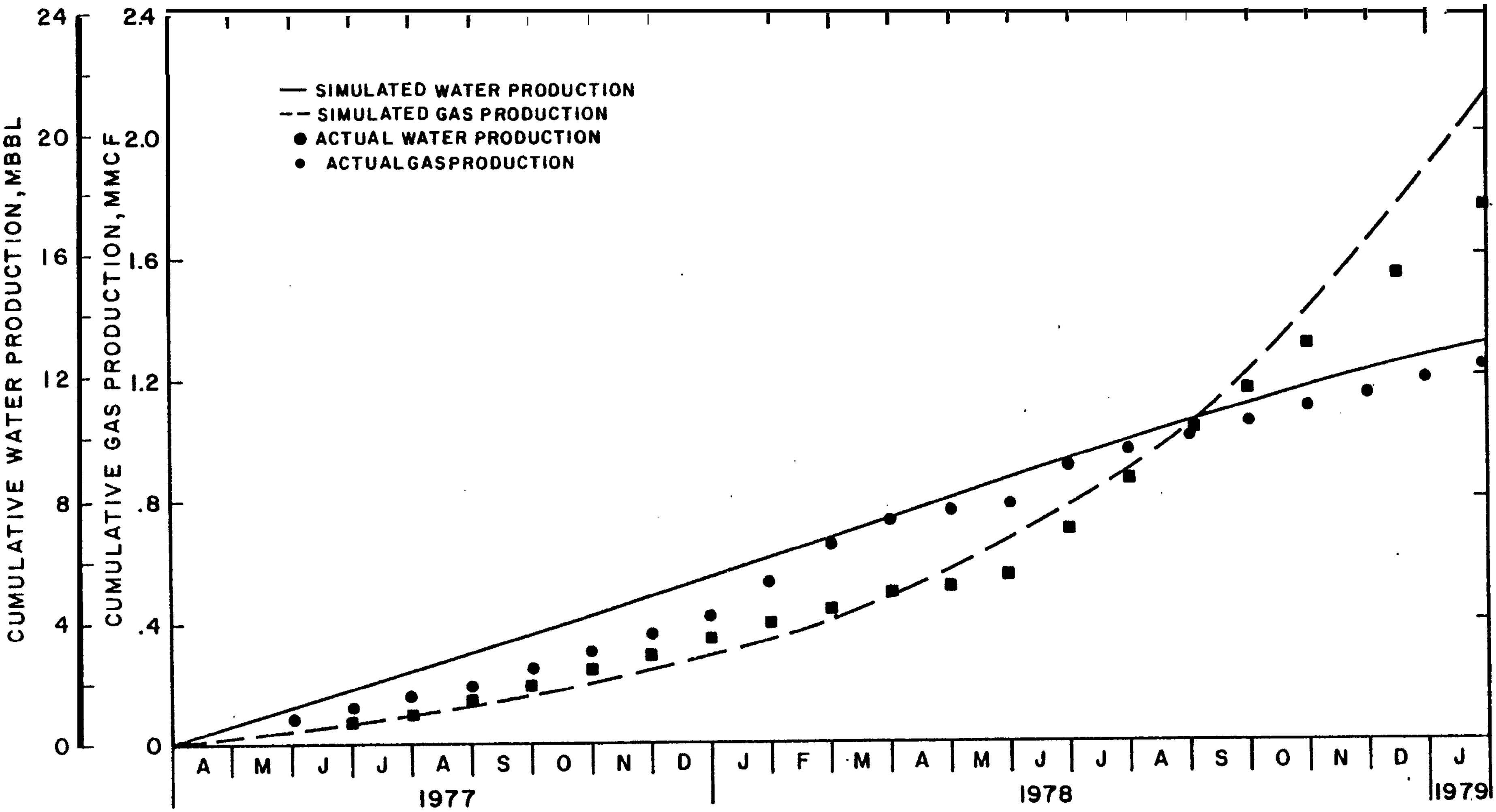
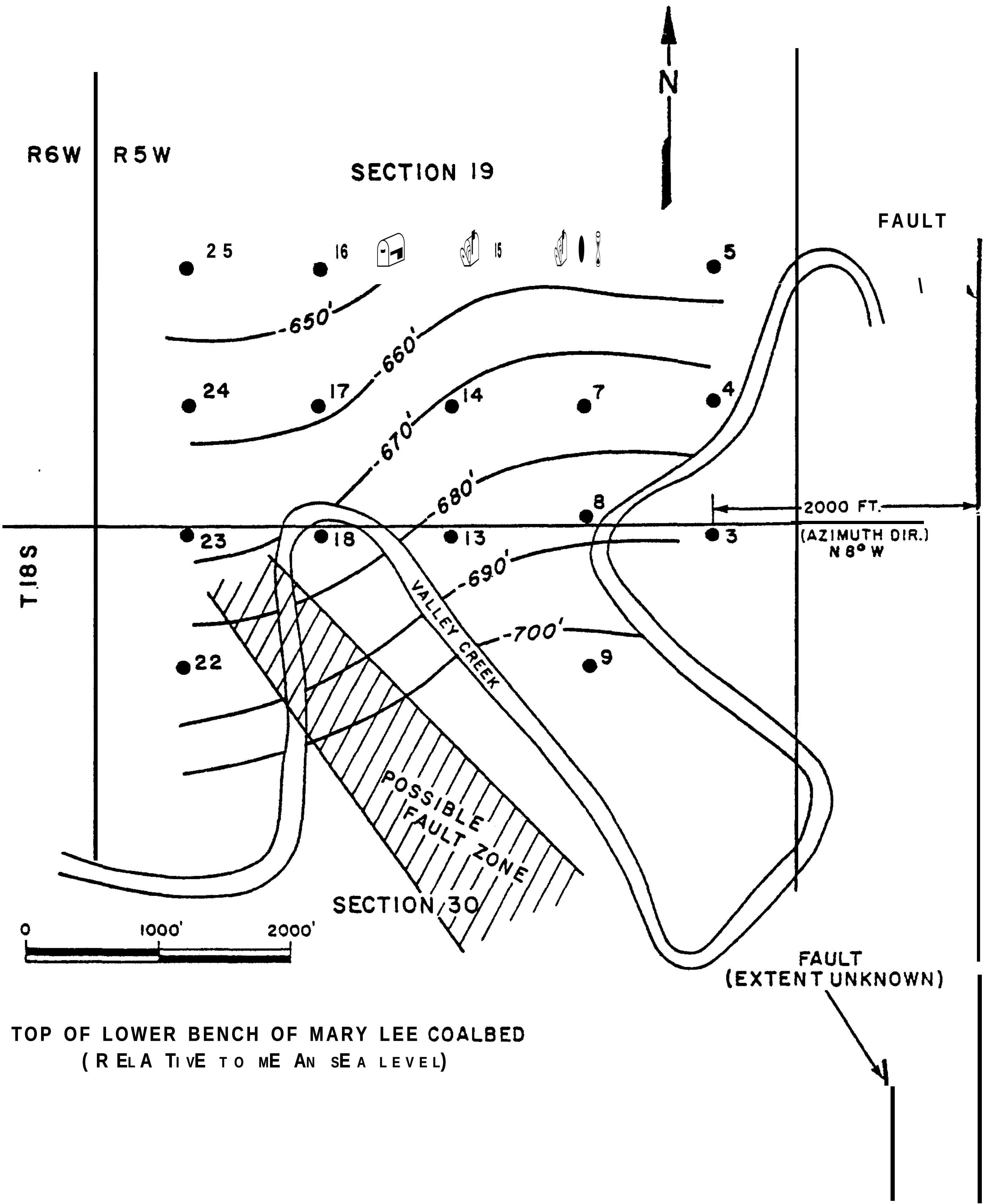


FIGURE 8
OAK GROVE DEGASIFICATION PATTERN
MARY LEE COALBED, JEFFERSON CO., ALABAMA



TOP OF LOWER BENCH OF MARY LEE COALBED
(RELATIVE TO MEAN SEA LEVEL)

FIGURE 9
TOTAL PATTERN PRODUCTION DATA
OAK GROVE PATTERN

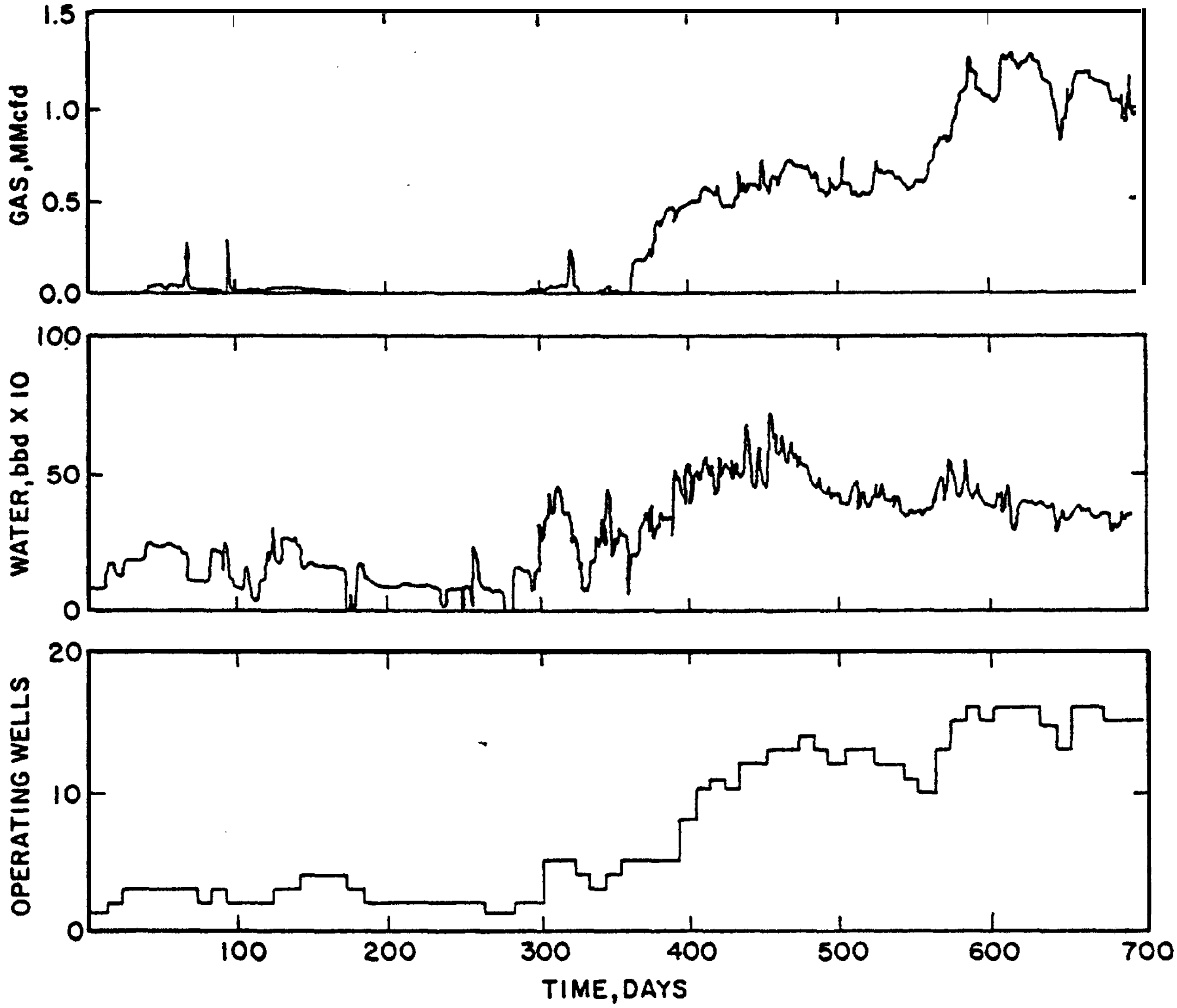


FIGURE 10

GRID USED IN OAK GROVE SIMULATION MODEL SHOWING AREAS OF ADJUSTED PERMEABILITY AND POROSITY

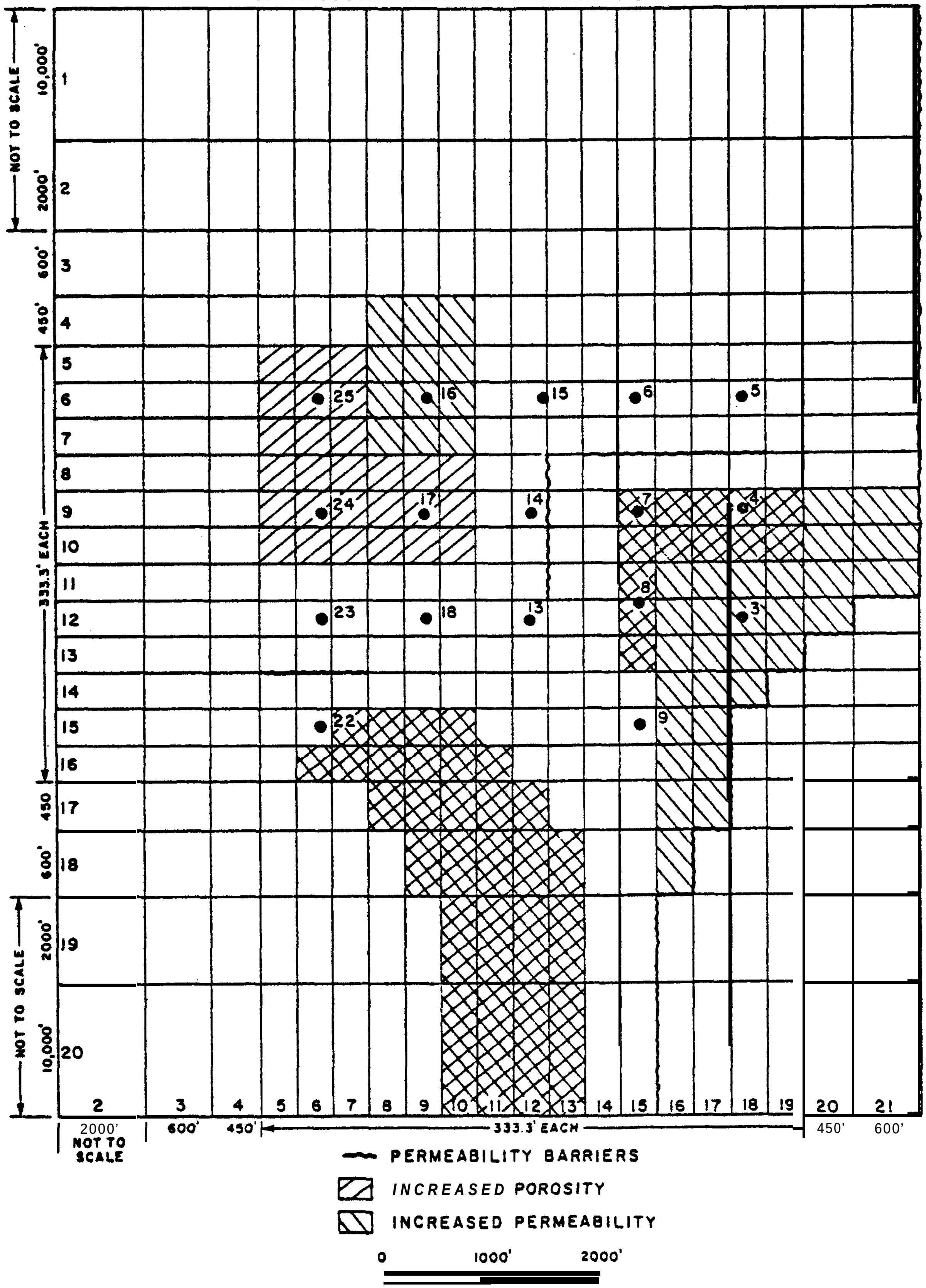


FIGURE 11
RELATIVE PERMEABILITY CURVES USED IN
OAK GROVE PATTERN SIMULATION

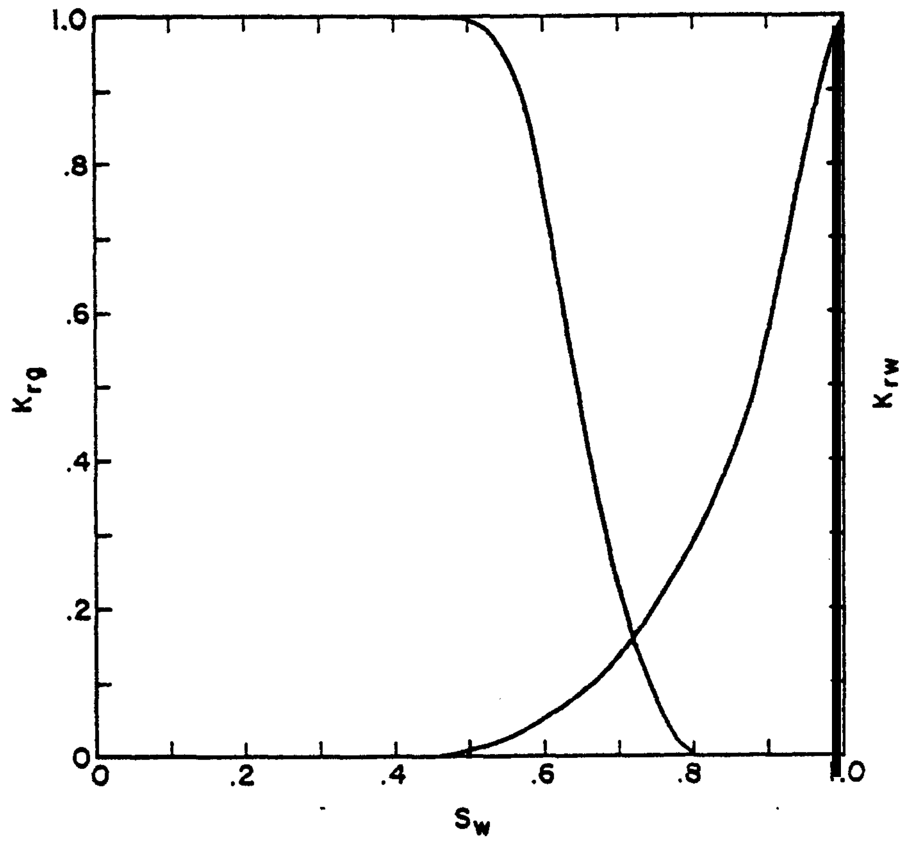


FIGURE 12

TOTAL PRODUCTION RATE FROM OAK GROVE PATTERN COMPARED TO SIMULATION RESULTS

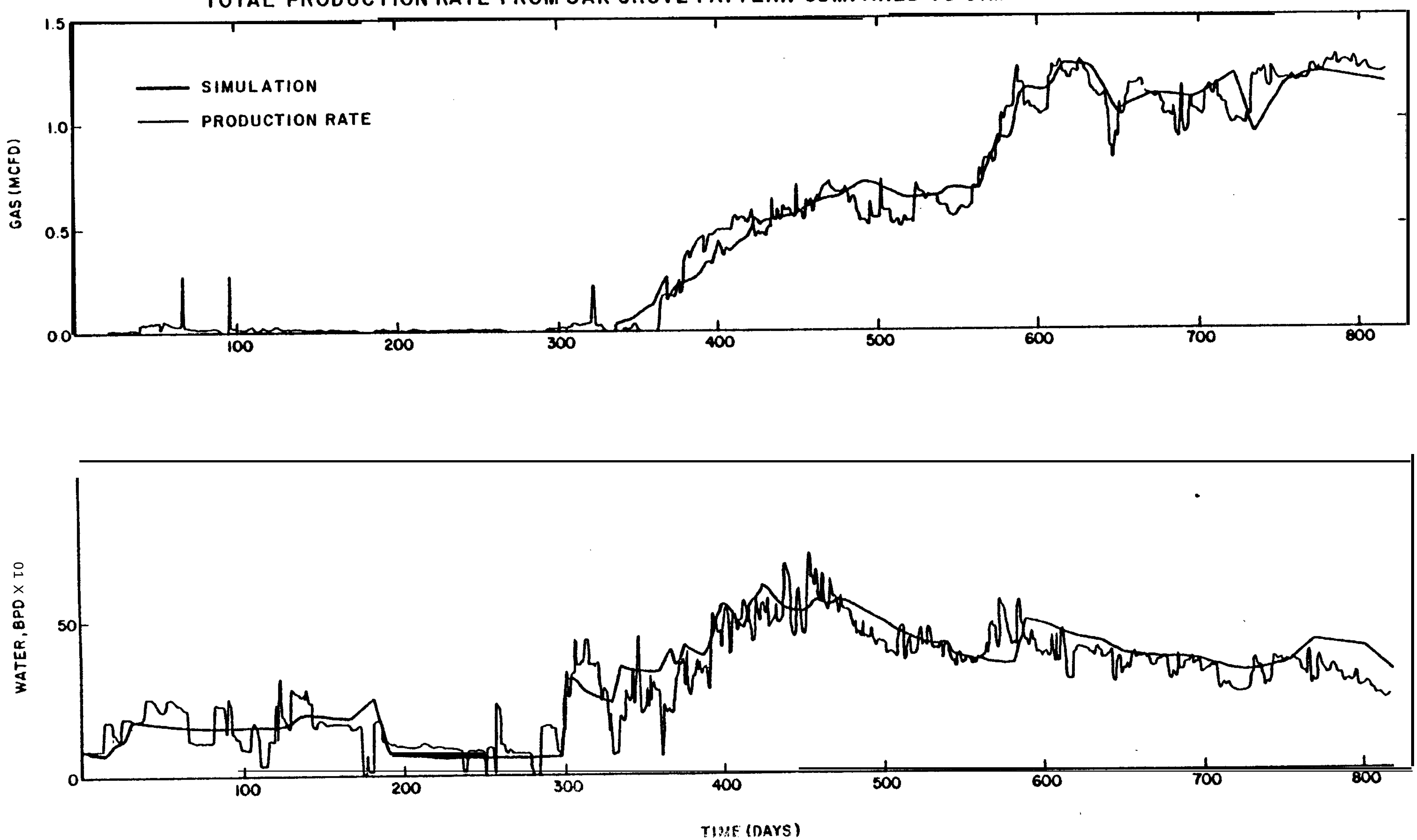


FIGURE 13
OAK GROVE WELL 3 PRODUCTION RATES COMPARED TO SIMULATION

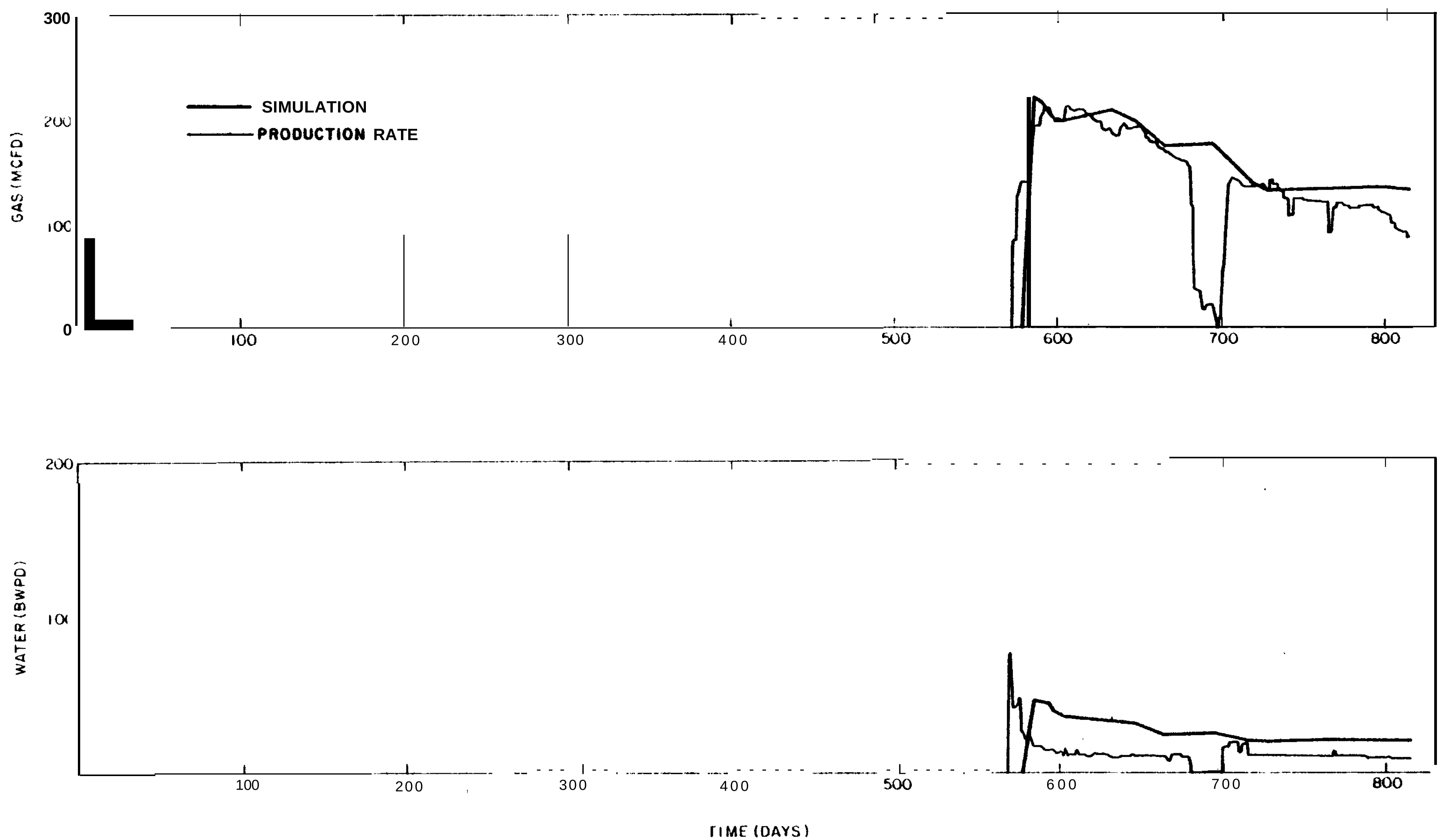


FIGURE 14
OAK GROVE WELL 4 PRODUCTION RATES COMPARED TO SIMULATION

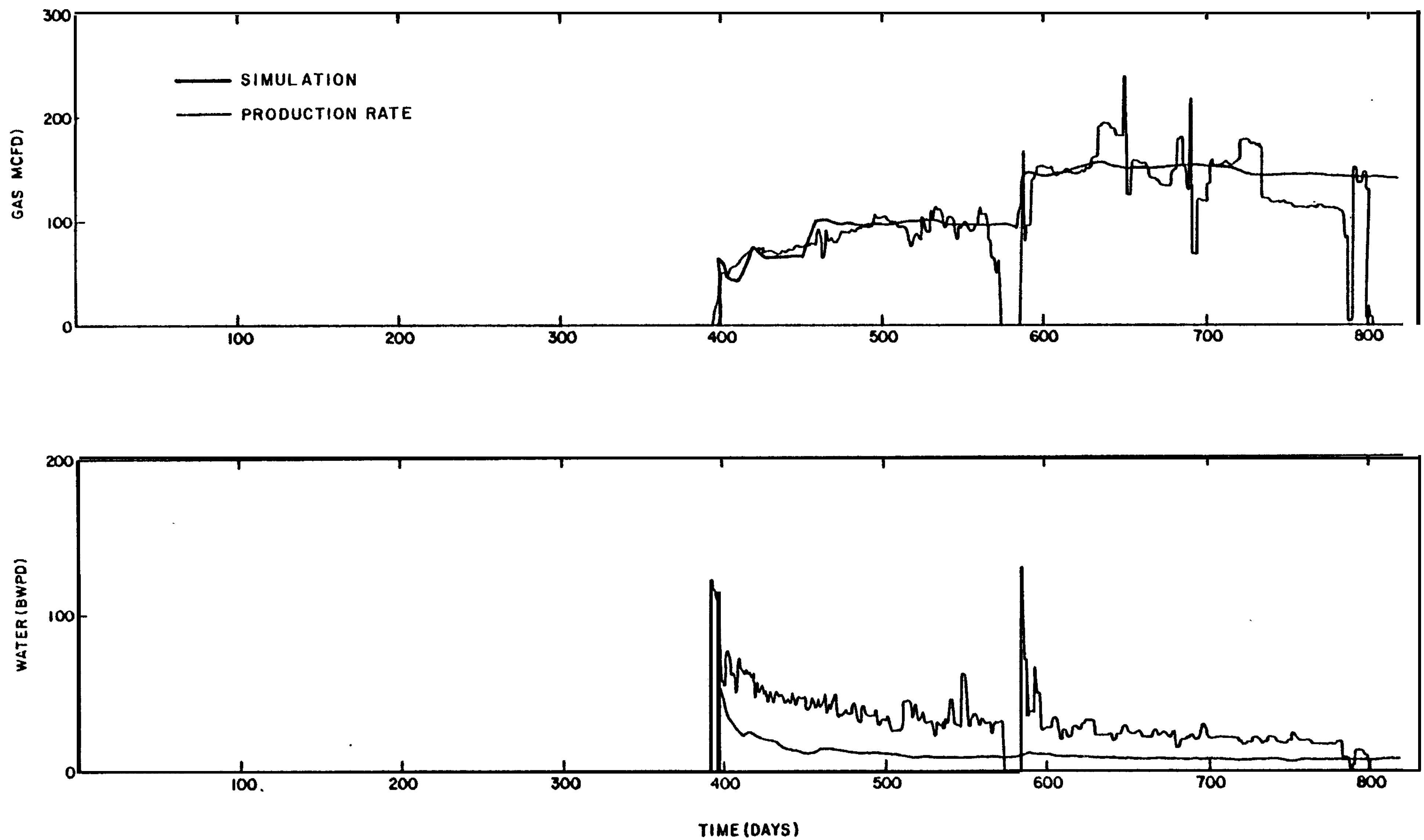


FIGURE 15
OAK GROVE WELL 5 PRODUCTION RATES COMPARED TO SIMULATION

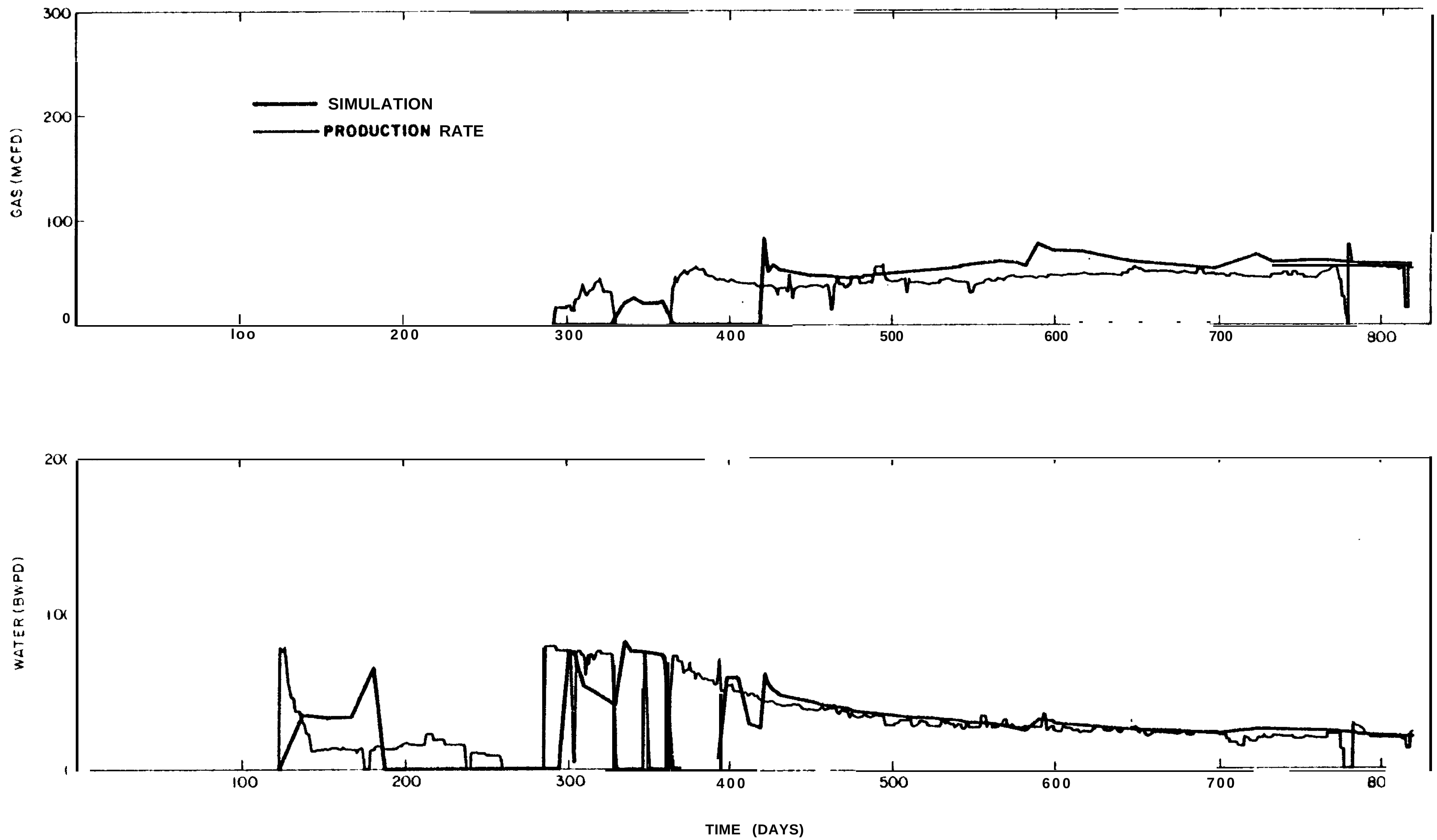


FIGURE 16
OAK GROVE WELL 6 PRODUCTION RATES COMPARED TO SIMULATION

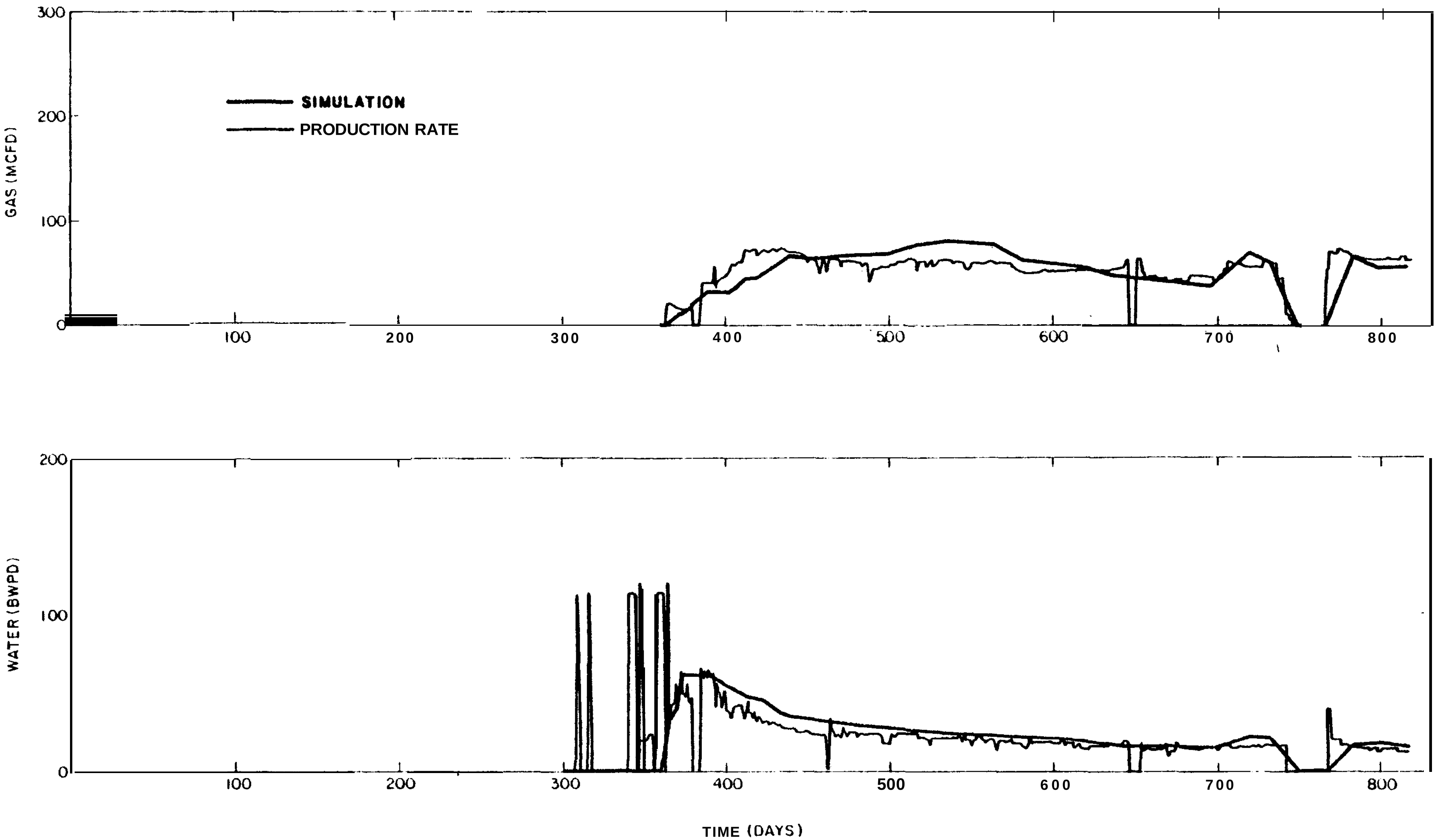


FIGURE 17
OAK GROVE WELL 7 PRODUCTION RATES COMPARED TO SIMULATION

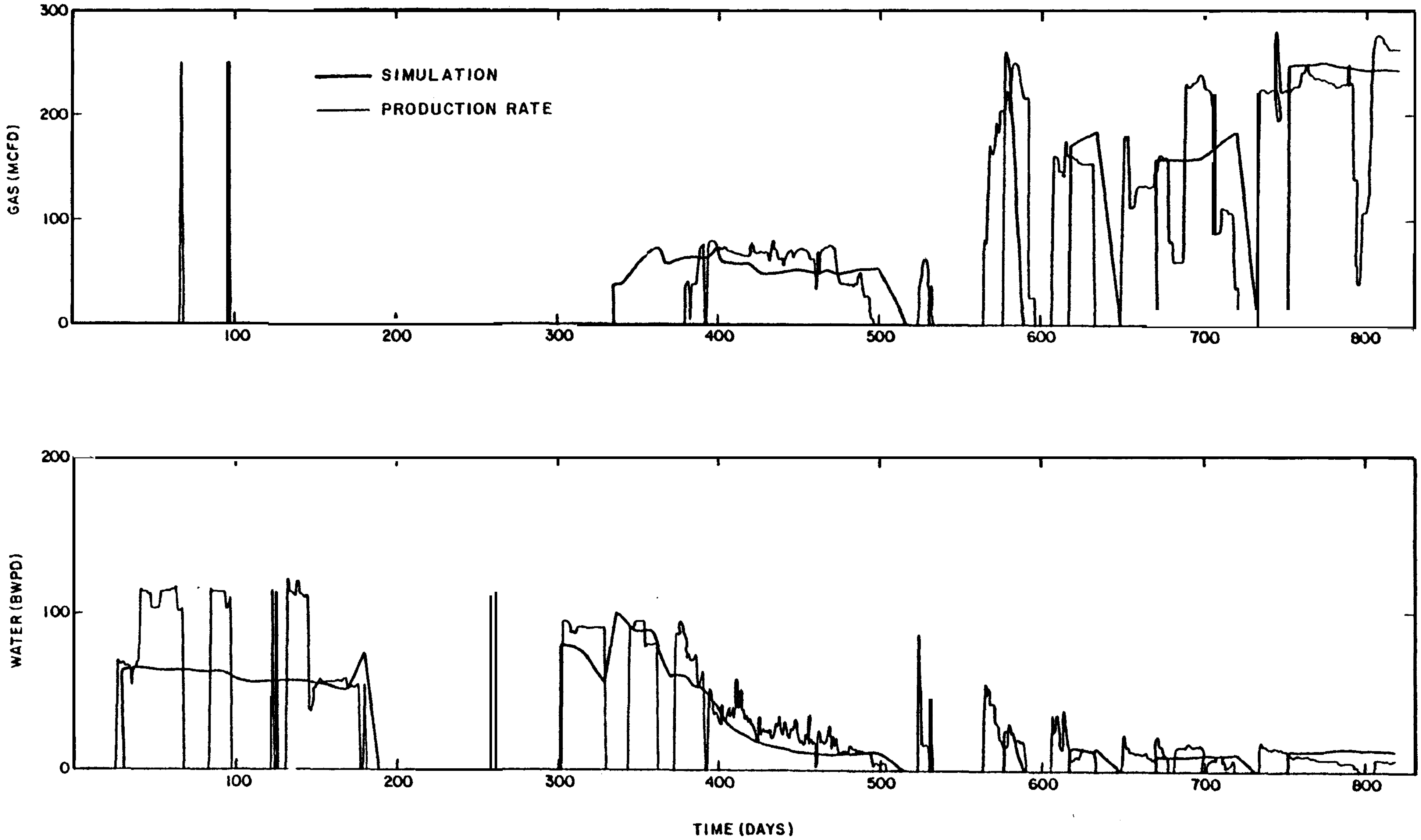


FIGURE 18
OAK GROVE WELL 8 PRODUCTION RATES COMPARED TO SIMULATION

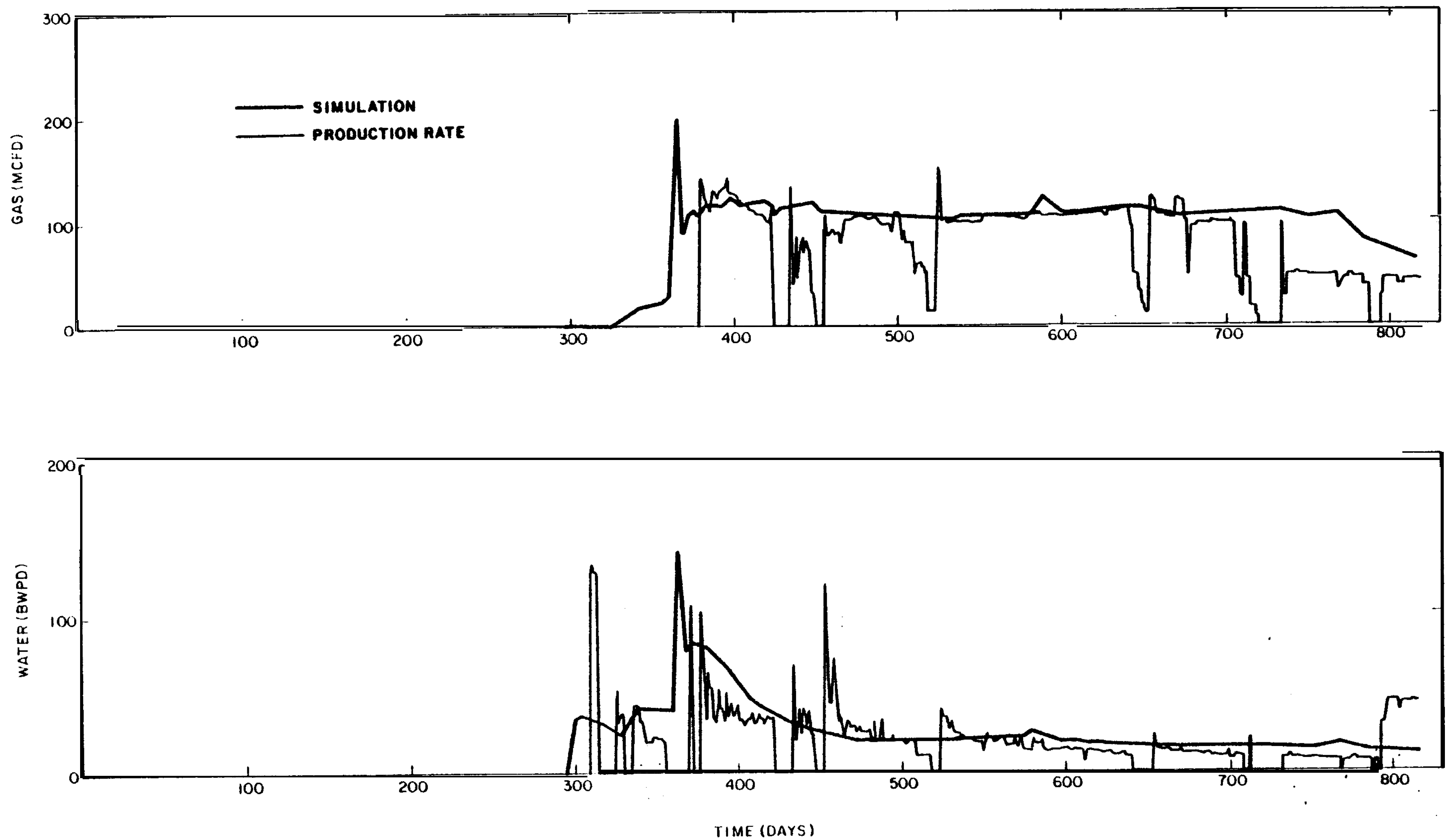


FIGURE 19
OAK GROVE WELL 9 PRODUCTION RATES COMPARED TO SIMULATION

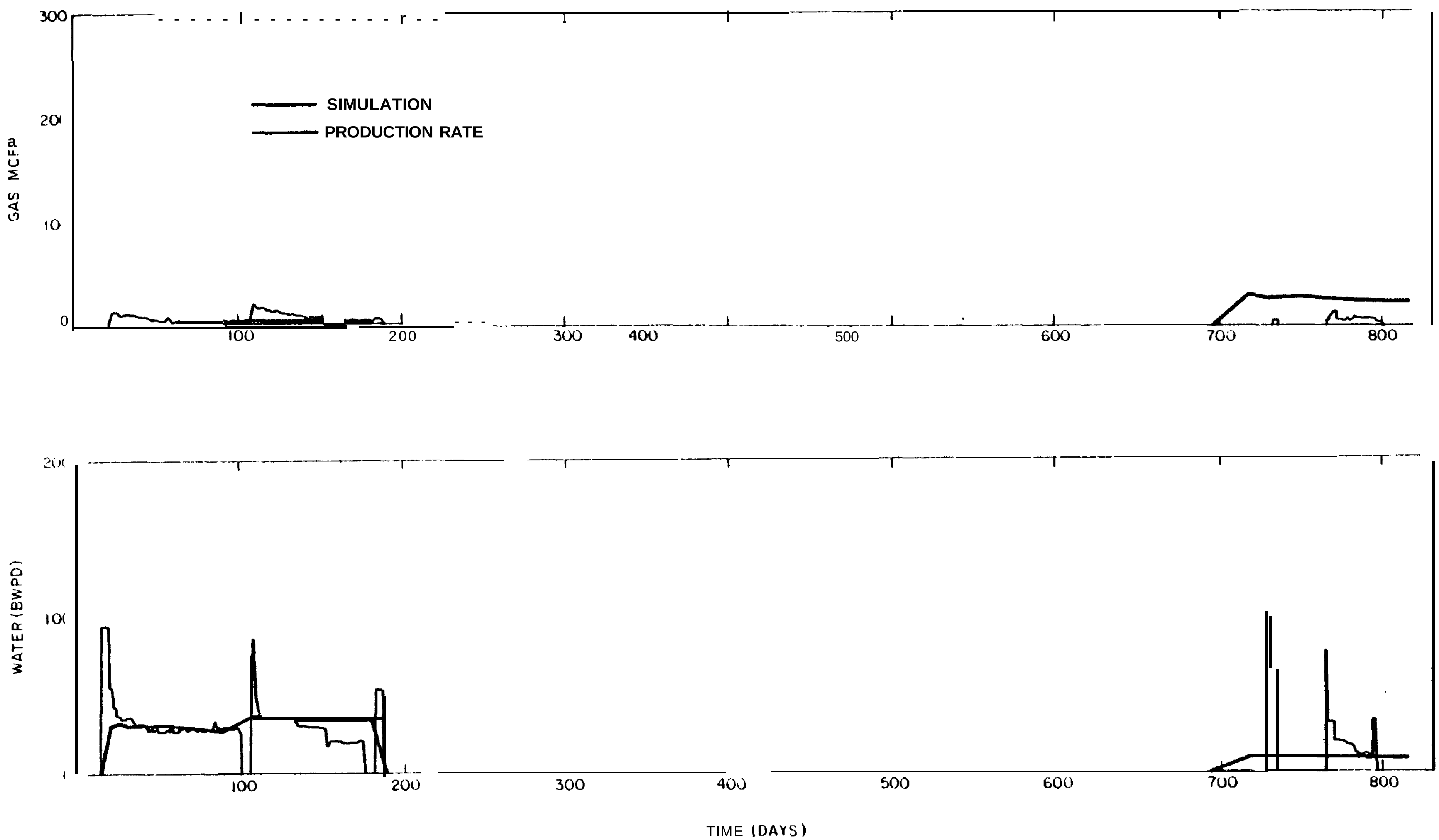


FIGURE 20
OAK GROVE WELL 13 PRODUCTION RATES COMPARED TO SIMULATION

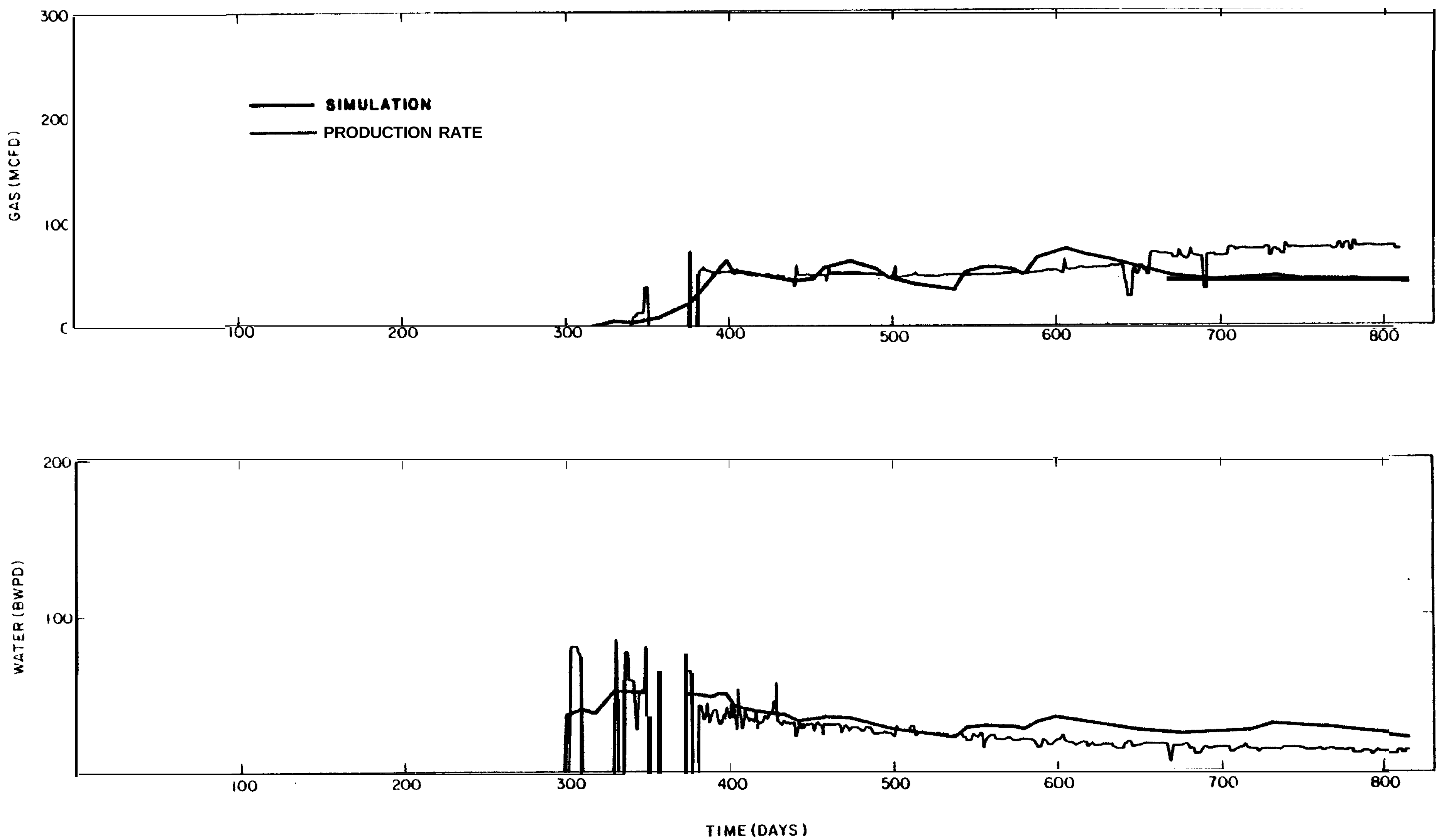


FIGURE 21
OAK GROVE WELL 14 PRODUCTION RATES COMPARED TO SIMULATION

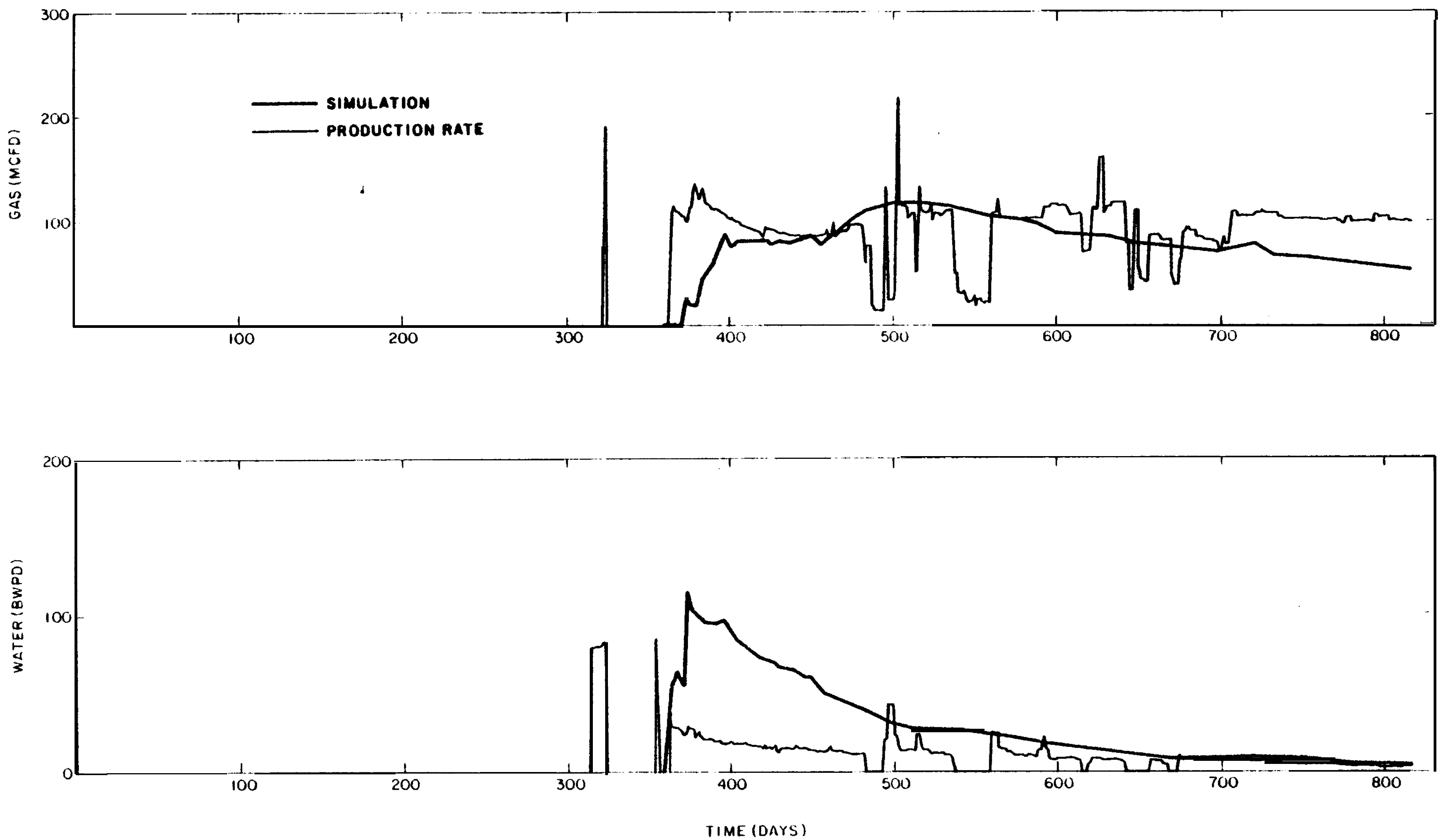


FIGURE 22
OAK GROVE WELL 15 PRODUCTION RATES COMPARED TO SIMULATION

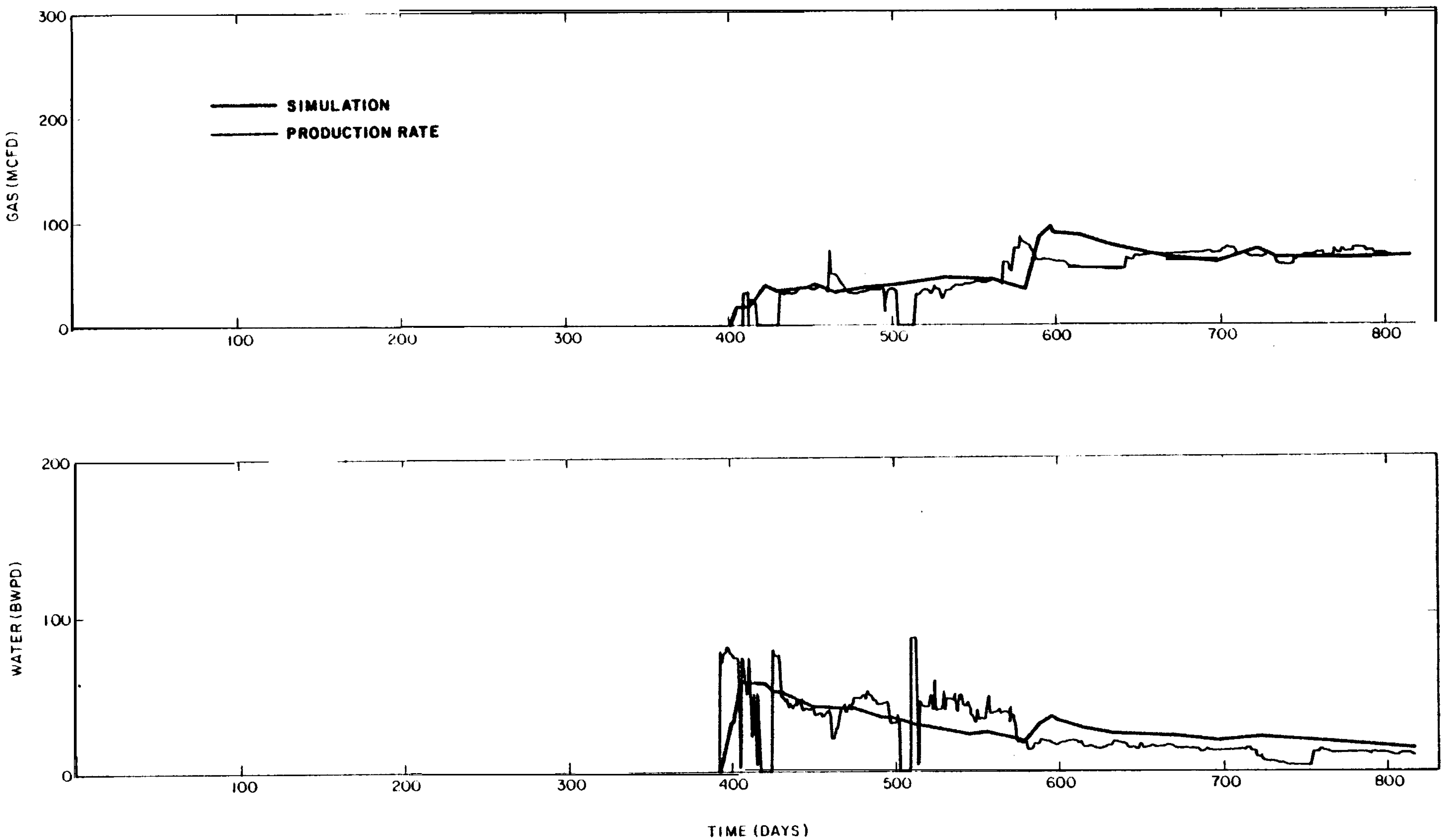


FIGURE 23
OAK GROVE WELL 16 PRODUCTION RATES COMPARED TO SIMULATION

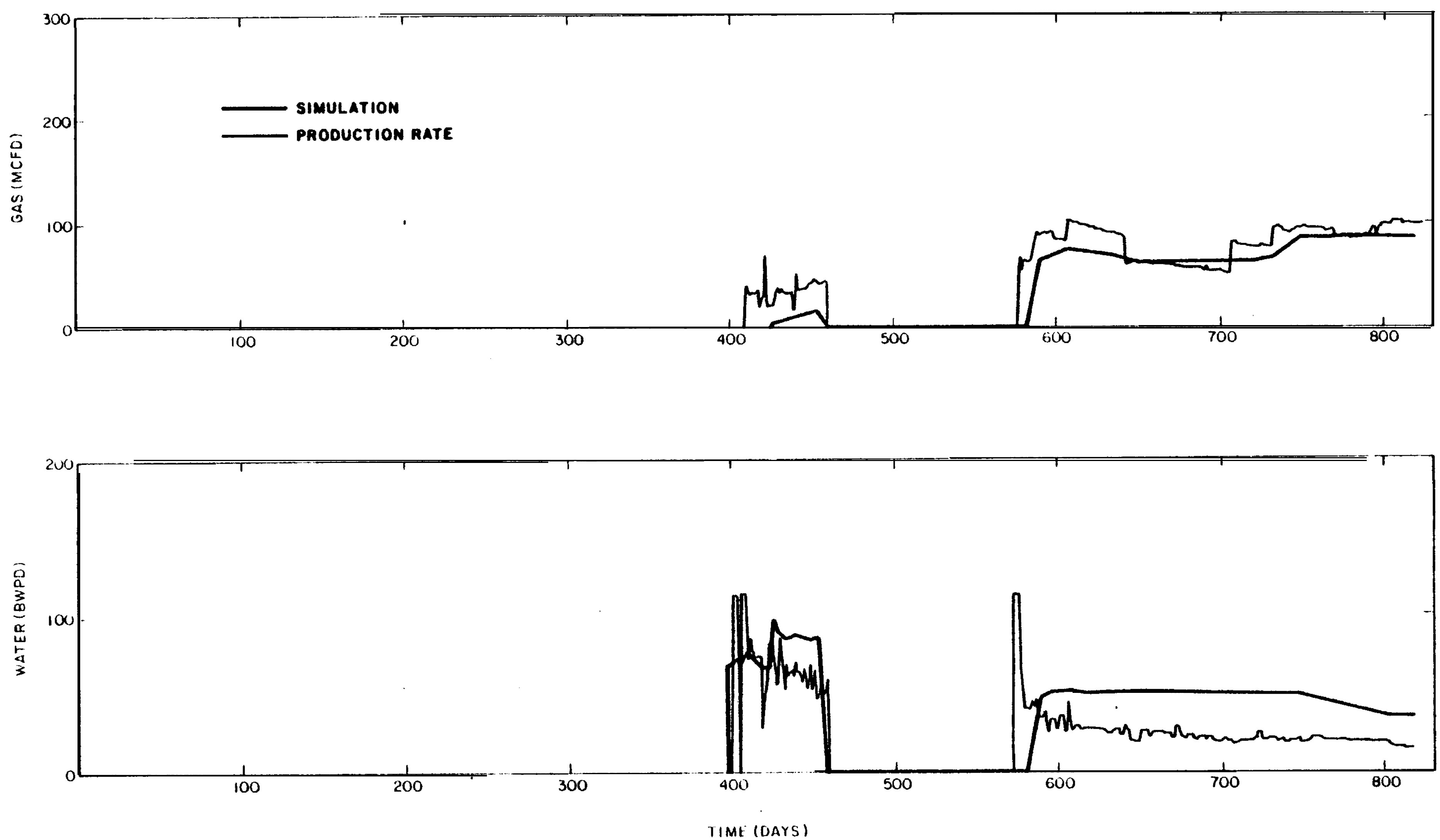


FIGURE 24
OAK **GROVE** WELL 17 **PRODUCTION** RATES COMPARED TO SIMULATION

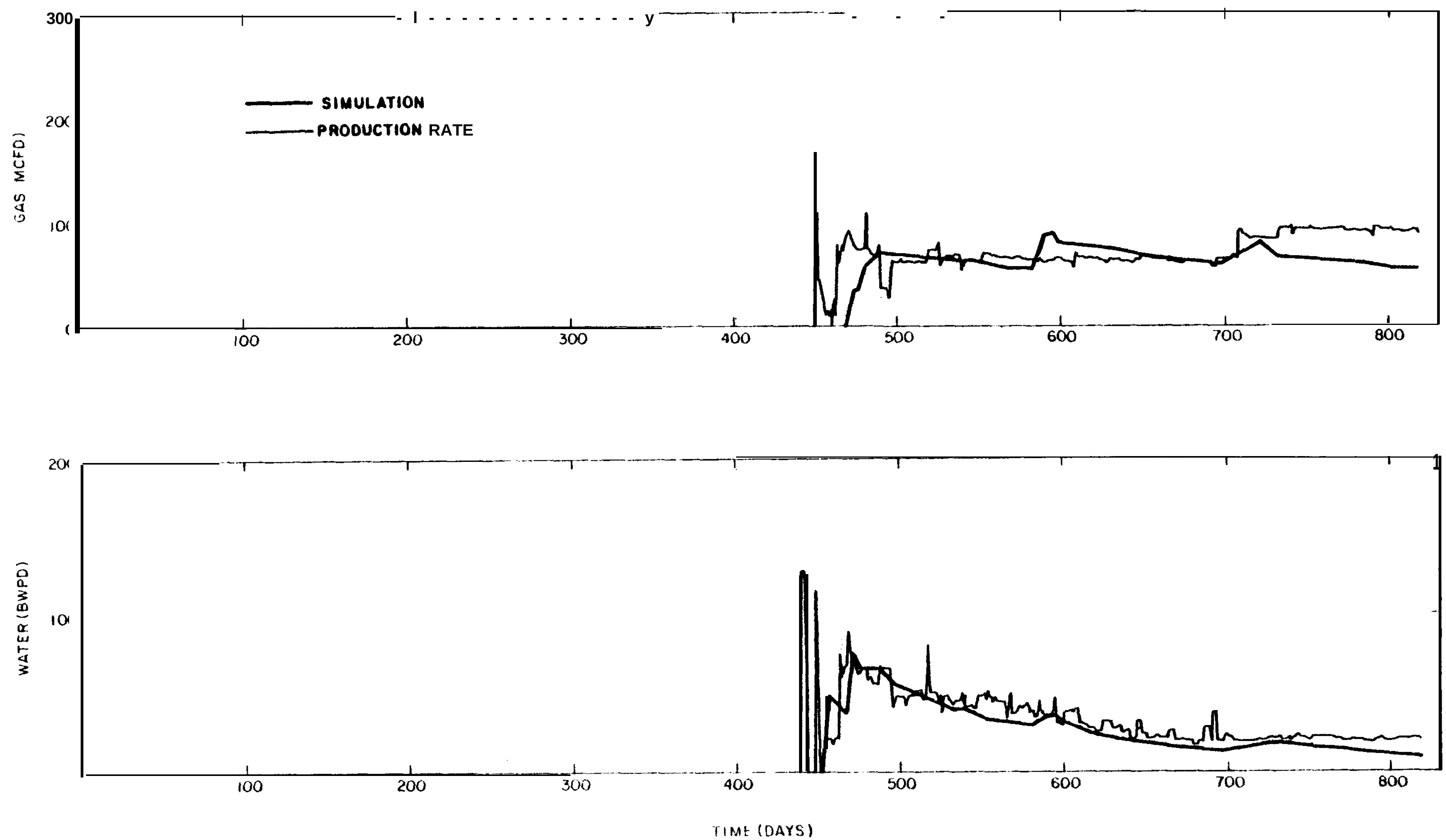


FIGURE 25
OAK GROVE WELL 18 PRODUCTION RATES COMPARED TO SIMULATION

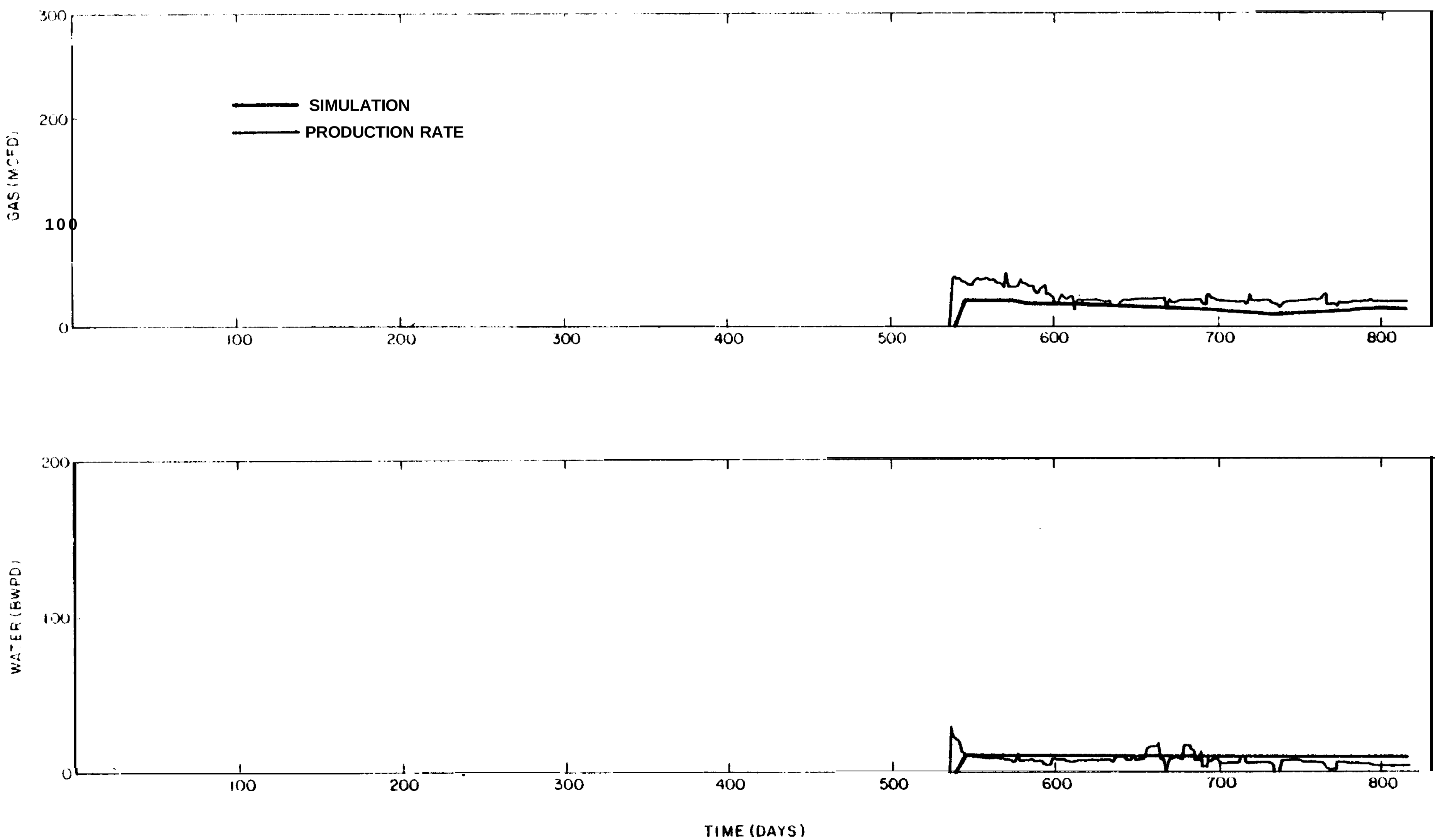


FIGURE 26
OAK GROVE WELL 22 PRODUCTION RATES COMPARED TO SIMULATION

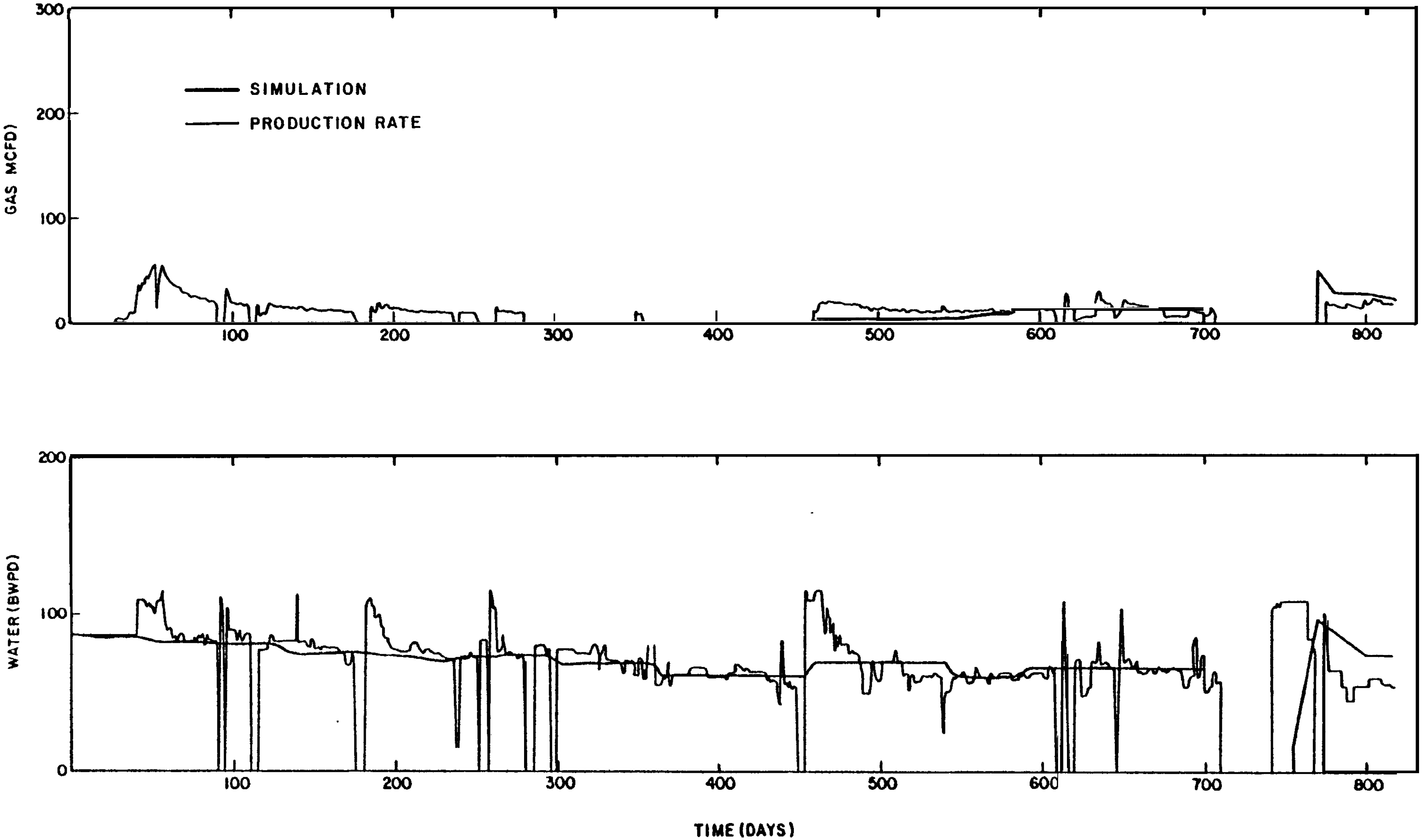


FIGURE 27
OAK GROVE WELL 23 PRODUCTION RATES COMPARED TO SIMULATION

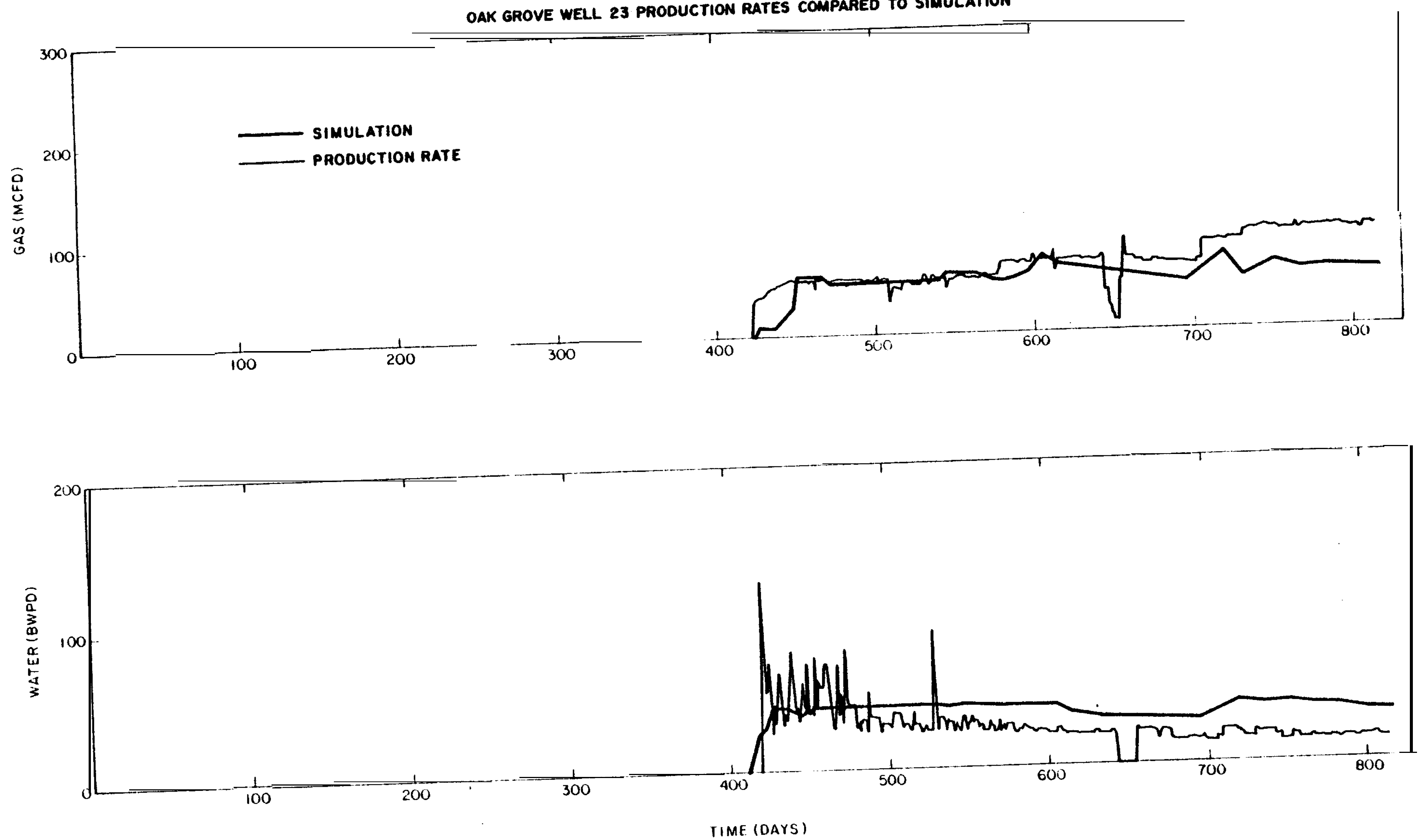


FIGURE 28
OAK GROVE WELL 24 PRODUCTION RATES COMPARED TO SIMULATION

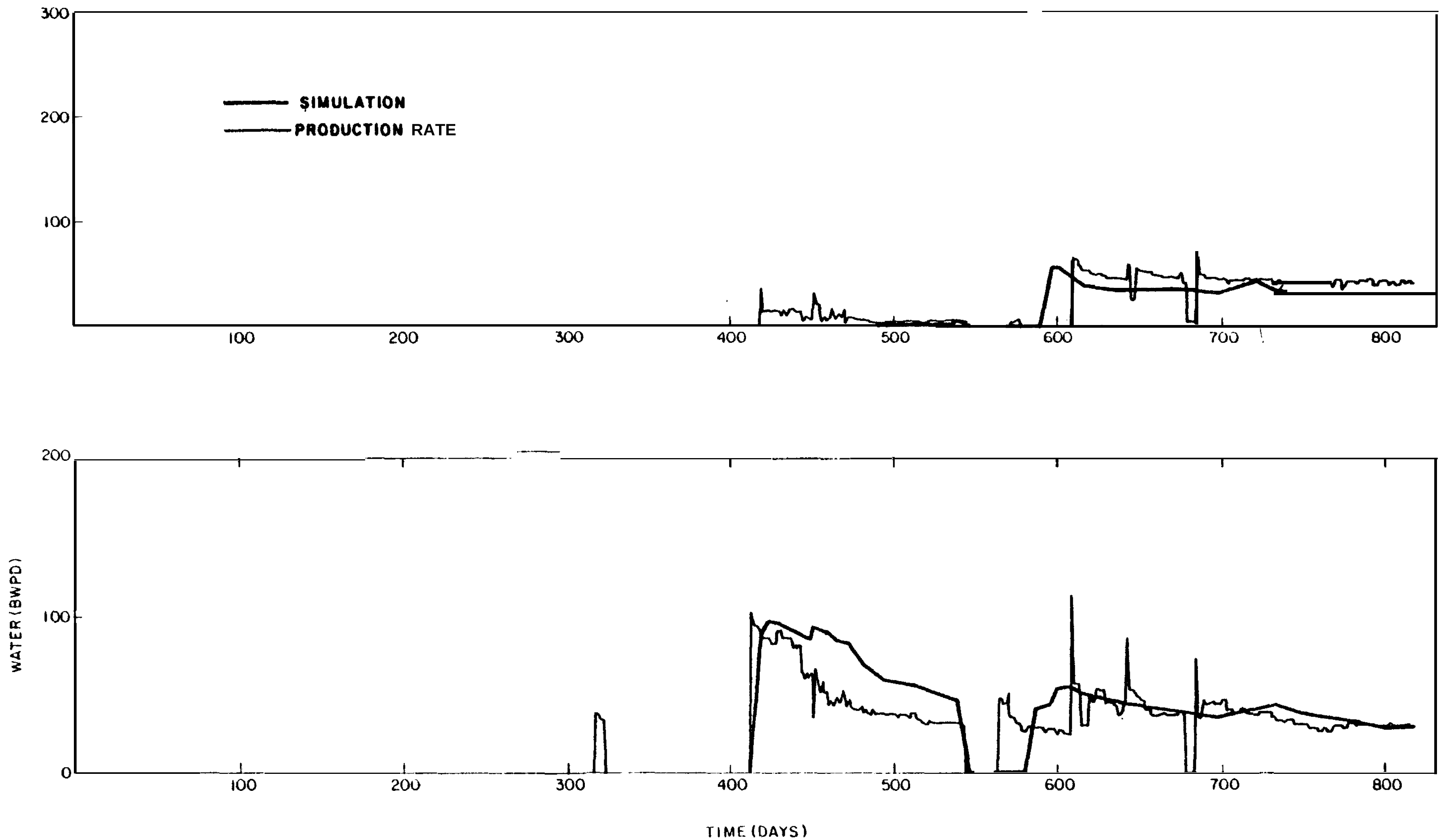


FIGURE 29

OAK GROVE WELL 25 PRODUCTION RATES COMPARED TO SIMULATION

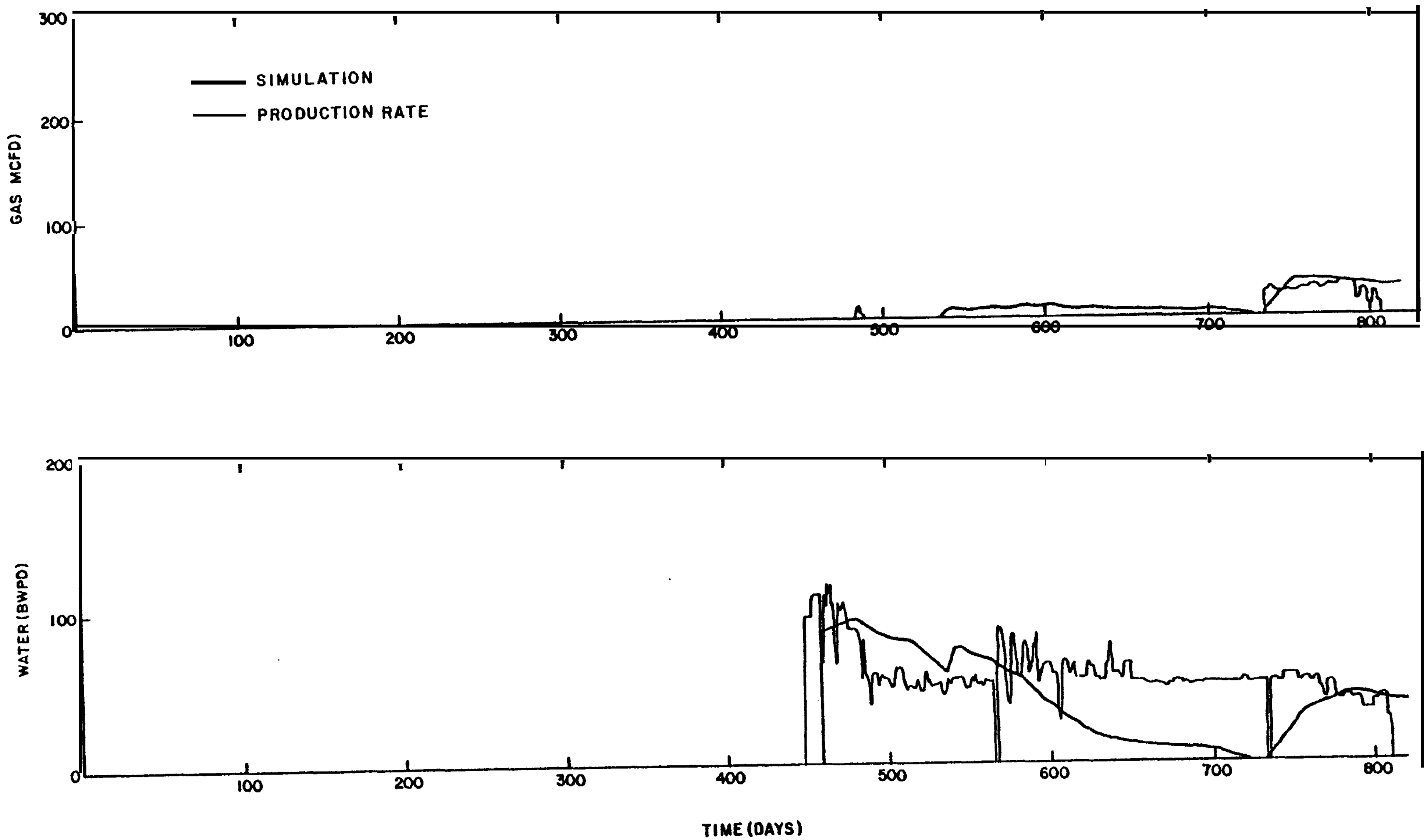


FIGURE 30
20 YEAR PREDICTION, OAK GROVE PATTERN

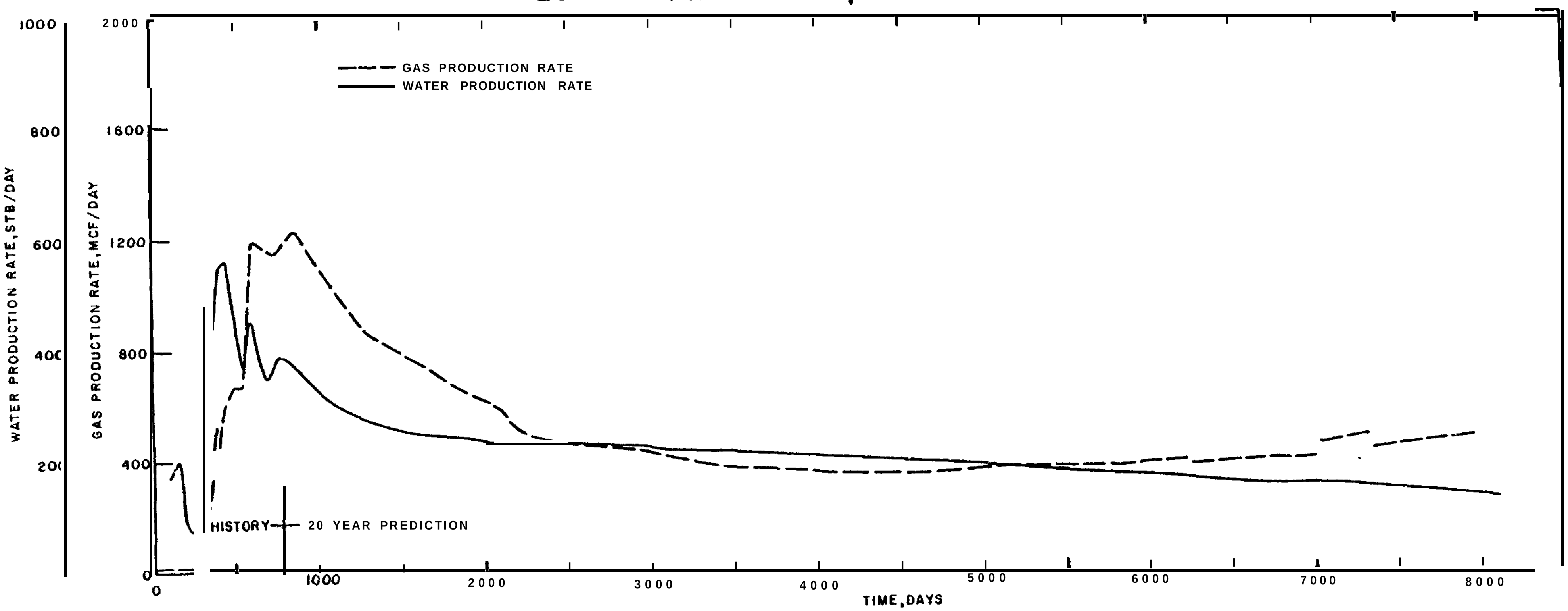


FIGURE 31
THE EFFECT OF WELL SPACING ON GAS PRODUCTION
USING OAK GROVE PATTERN DATA

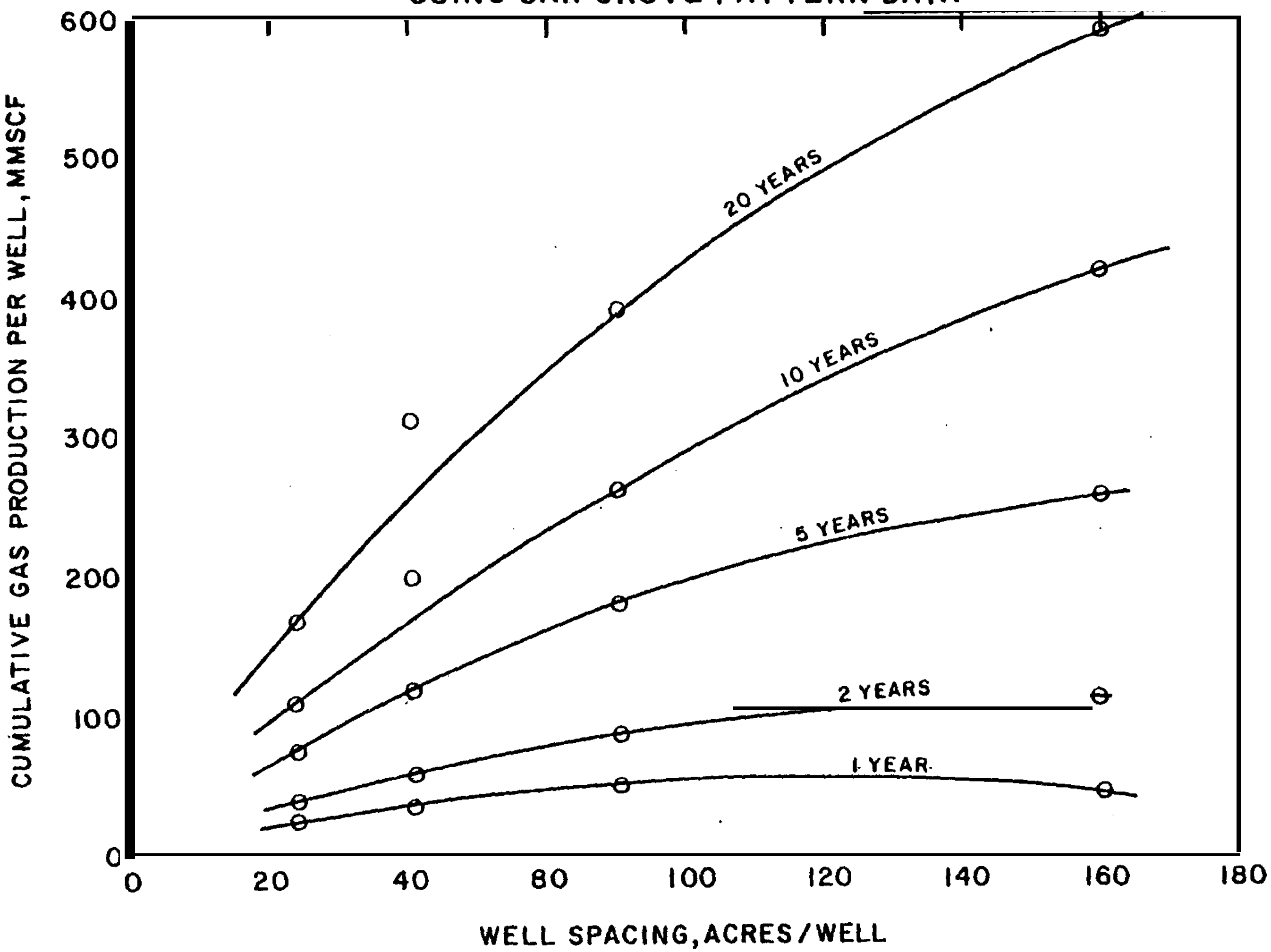


FIGURE 32

THE EFFECT OF WELL SPACING ON GAS RECOVERY FROM WITHIN THE WELL PATTERN USING OAK GROVE PATTERN DATA

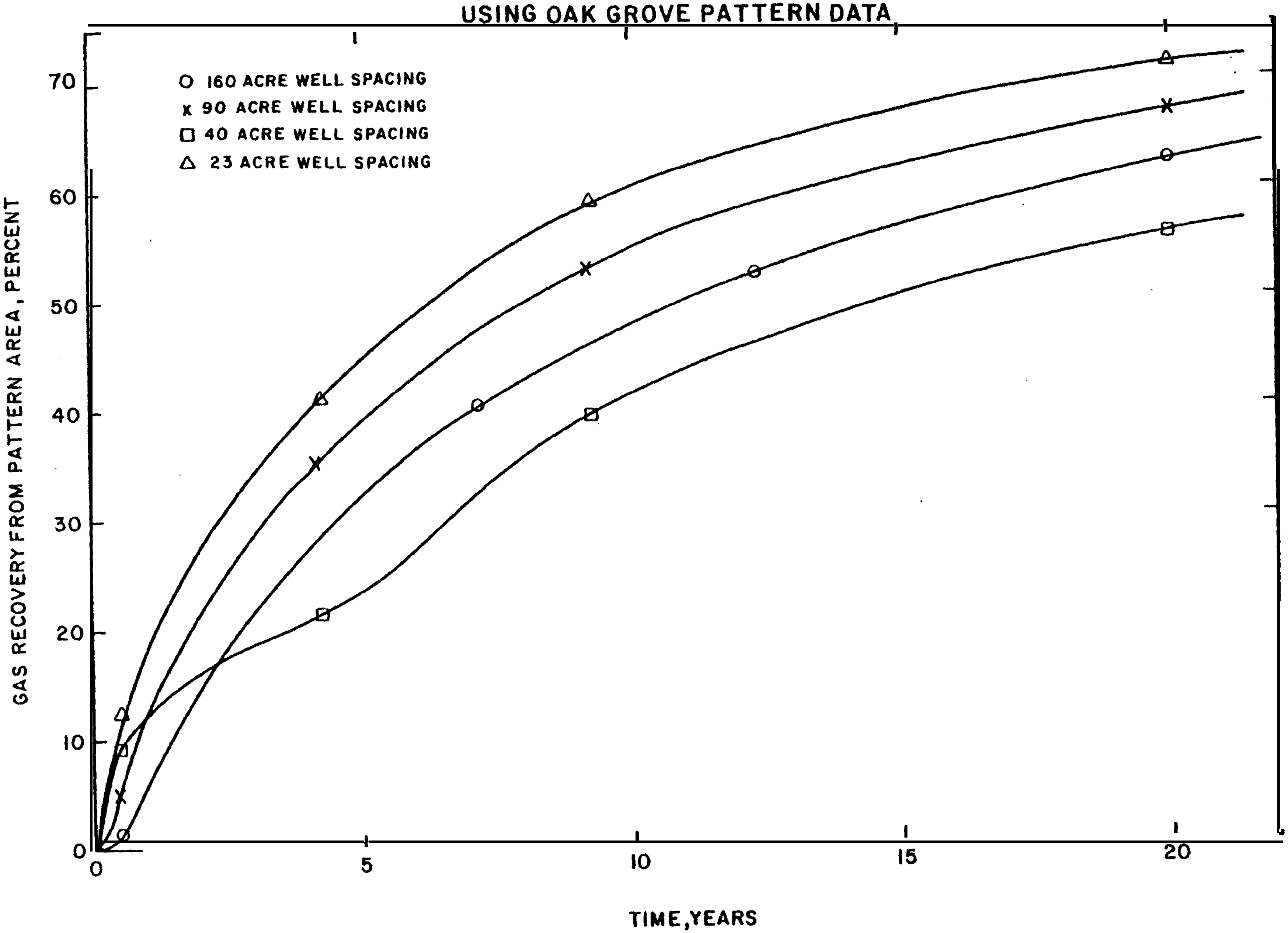


FIGURE 33

PRODUCTION WELL HISTORY DURING TESTING PERIOD

WELL 22, OAK GROVE PATTERN

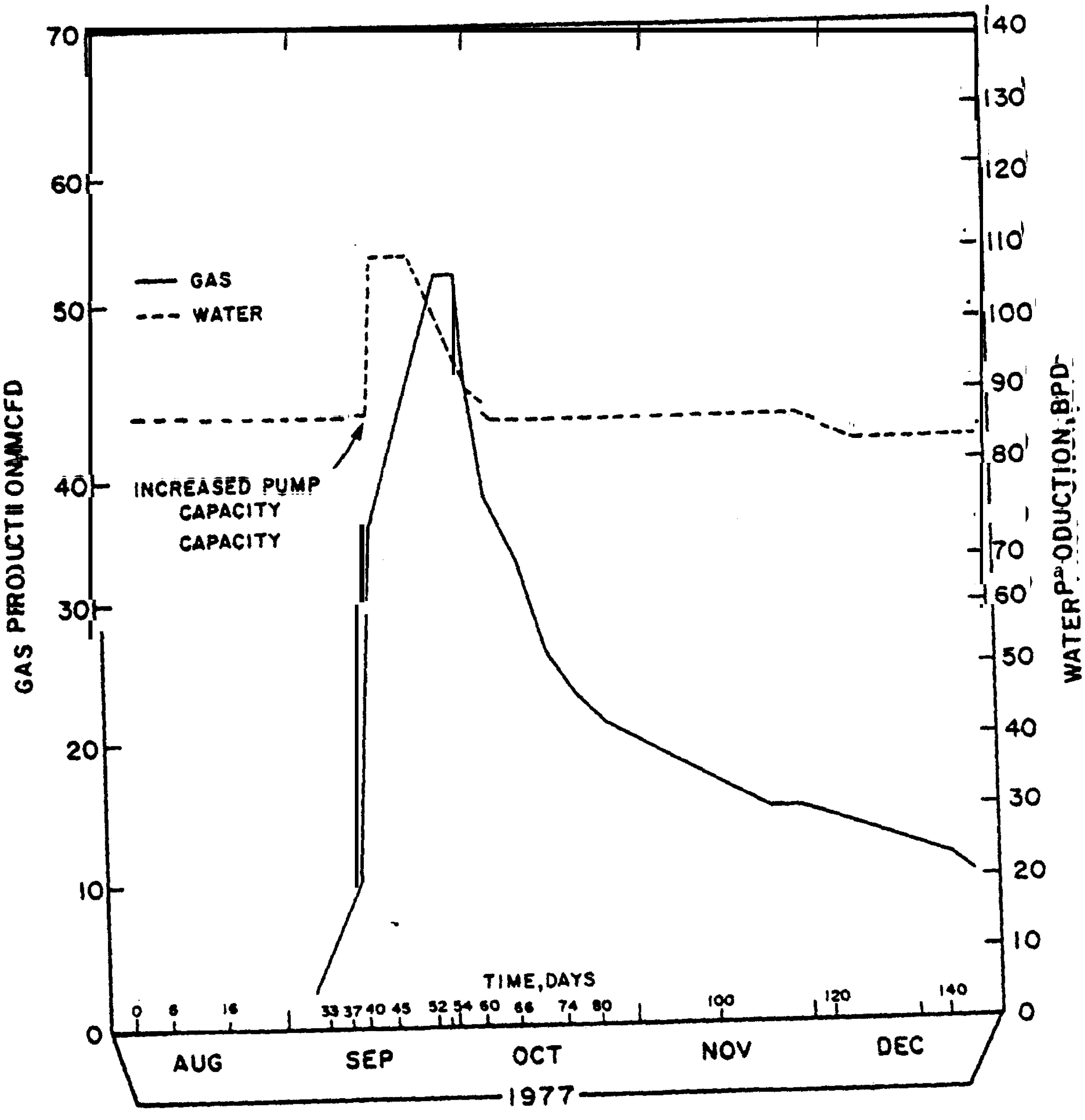


FIGURE 34

GAS PRODUCTION HISTORY MATCH-WELL 22,OAK GROVE PATTERN

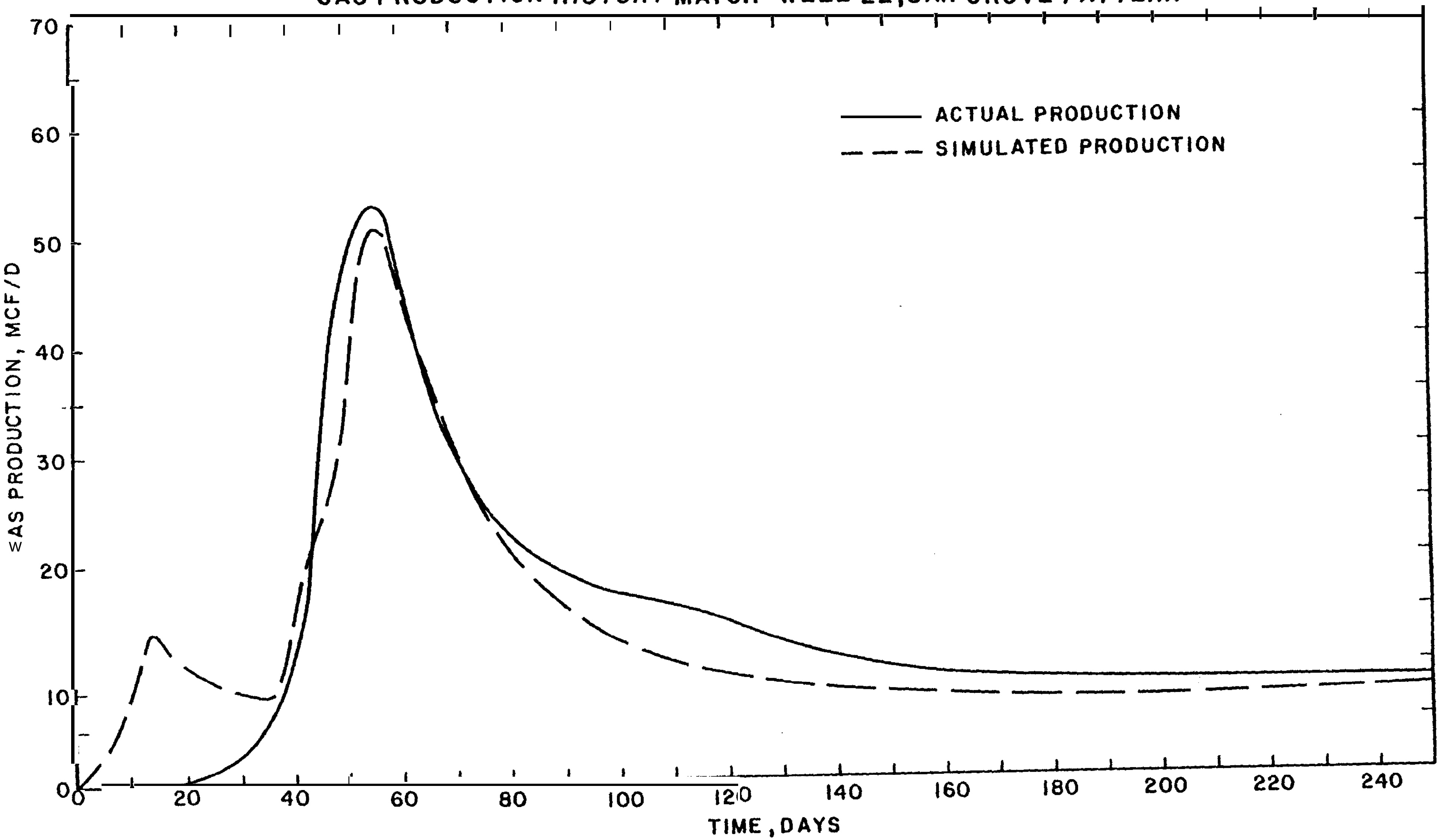


FIGURE 35
WELL 22 RELATIONSHIP TO HIGH PERMEABILITY FAULT ZONE

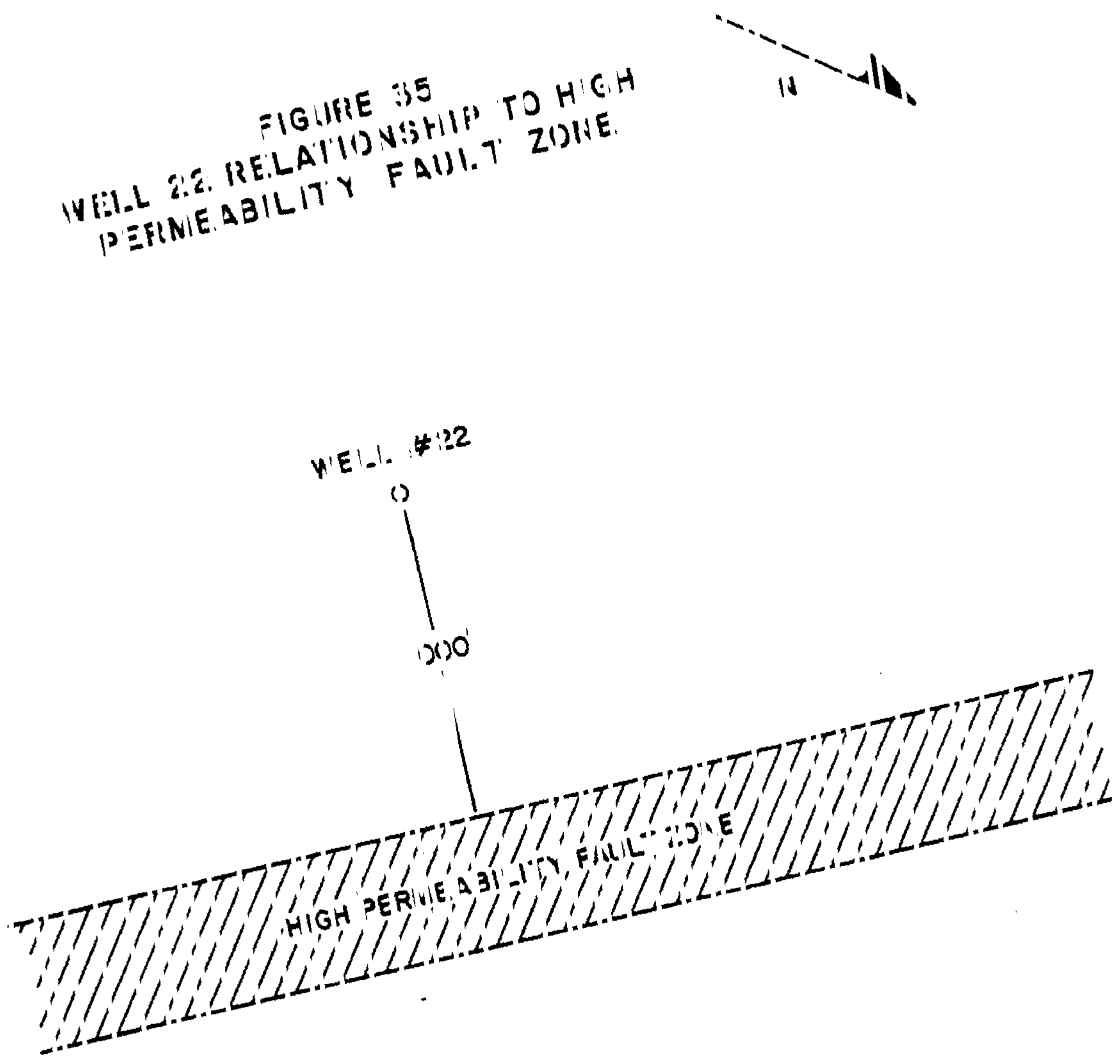


FIGURE 36
GAS CONTENT CONVERSION CHART
(FIVE SAMPLES FROM STONER NO.1 PLOTTED)

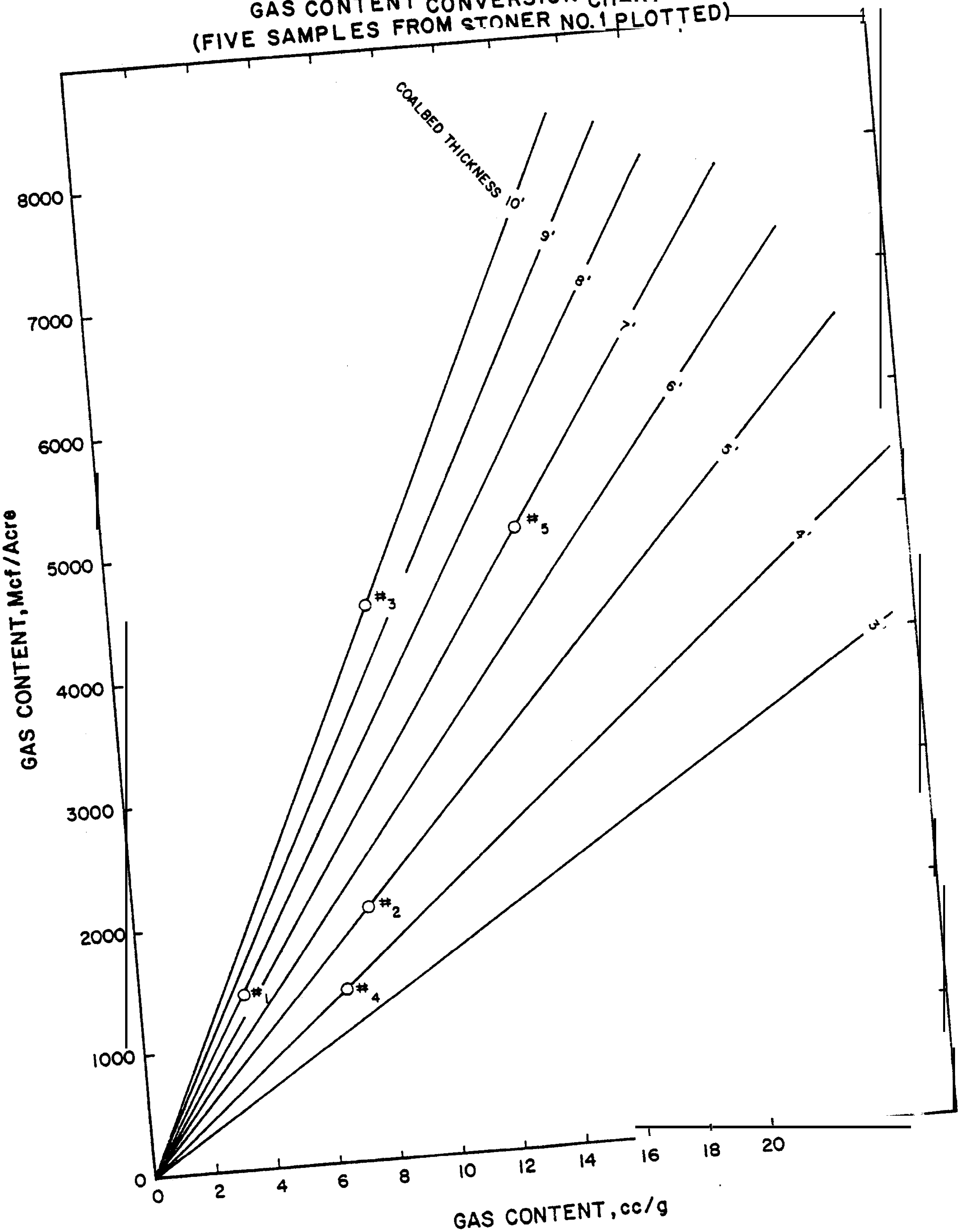


FIGURE 37
CORRELATION LOGS

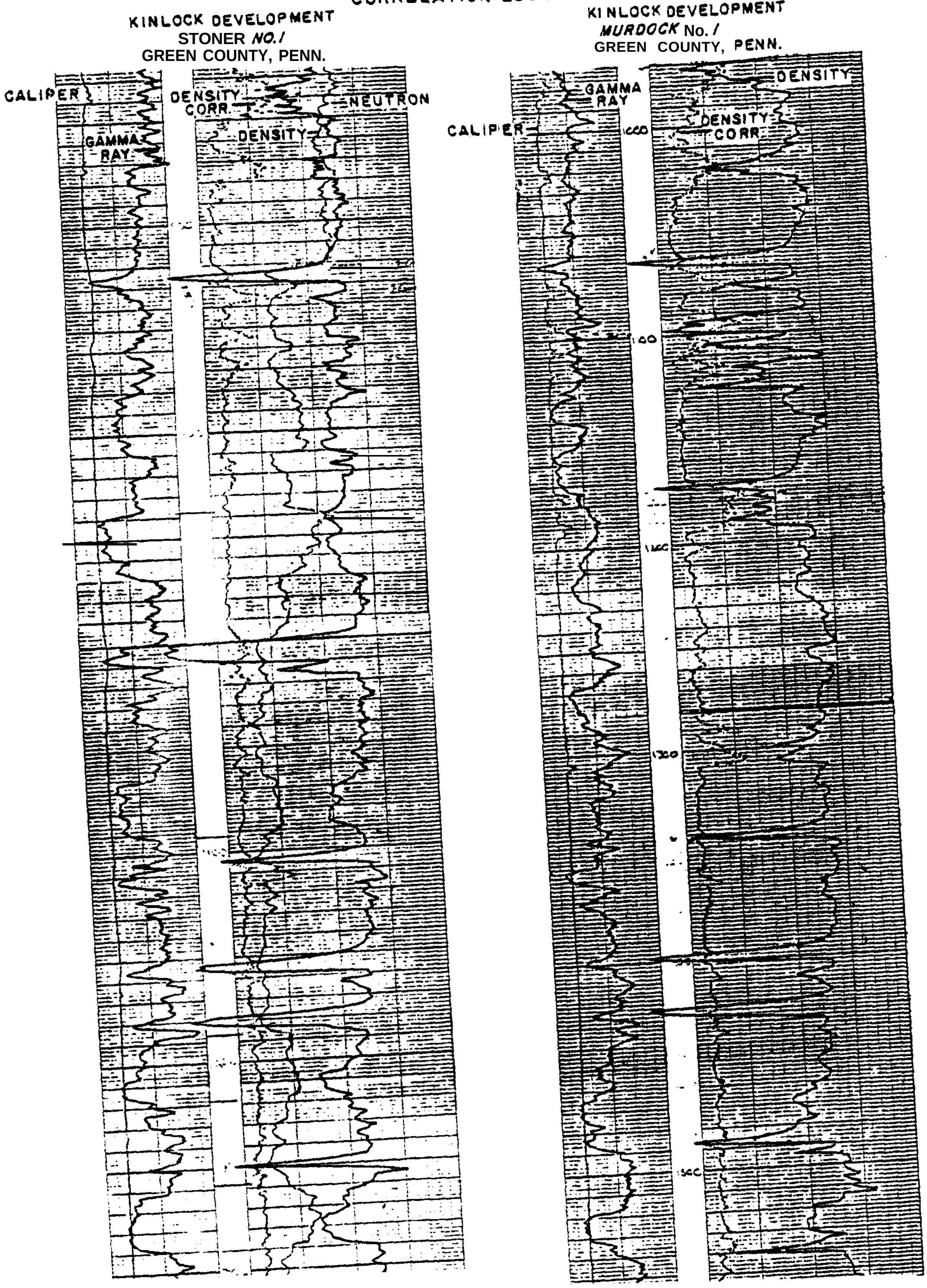


FIGURE 38
CONSTANT RATE INJECTION TEST - MURDOCK NO.1